CATSKILL WATER

1905 1917

BOARD OF WATER SUPPLY
NEW YORK CITY
1917

Catskill Water Supply

A GENERAL DESCRIPTION

AND

BRIEF HISTORY

BOARD OF WATER SUPPLY
OF THE CITY OF NEW YORK

OCTOBER, 1917

Ashokan aerator and the beginning of the Catskill aqueduct. The large building is the Screen chamber, at which the standard aqueduct begins. Following the aqueduct embankment, one comes first to the Gaging chamber and, to the left, the two chambers of the Esopus steel-pipe siphon. The Lower gate-chamber is just out of the picture at the right.

New York's Catskill Mountain Water Supply

A NOTABLE CIVIC ACHIEVEMENT

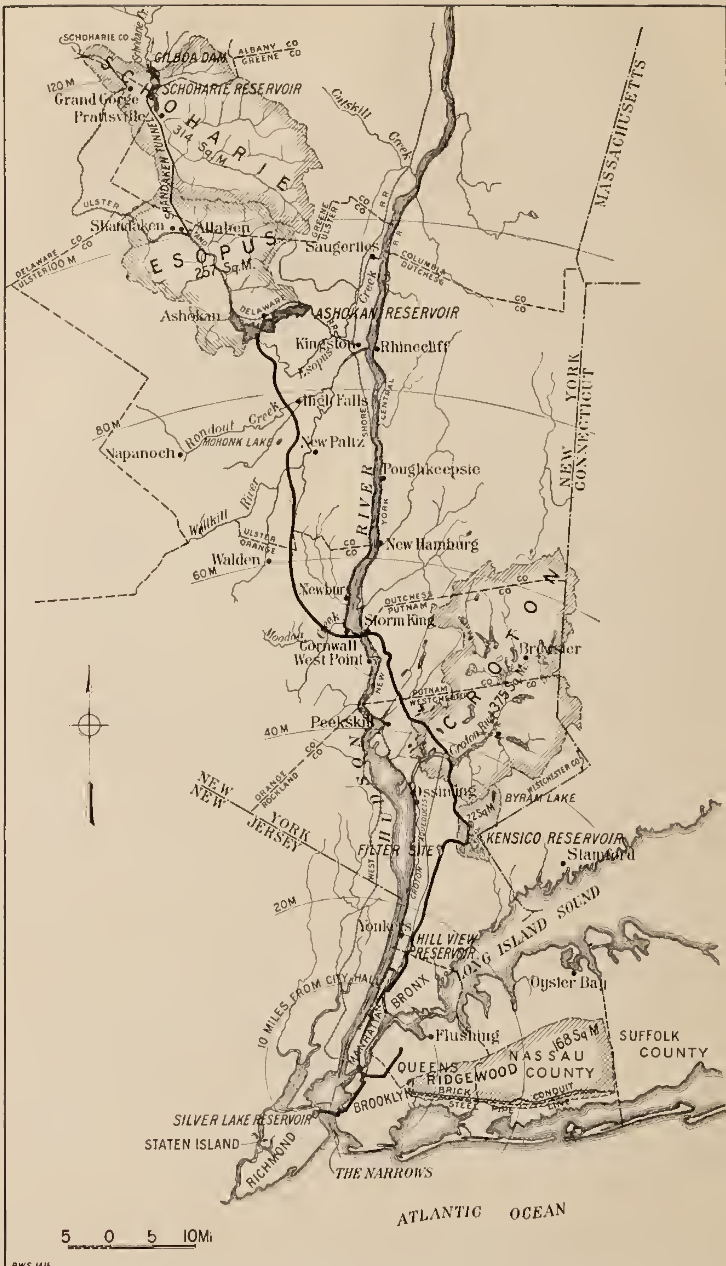
A dream of many years ago has been realized in one of the greatest of civic achievements! Catskill Mountain water has been led to New York City. More or less extensively and intermittently since the latter months of 1915, and uninterruptedly since May, 1917, it has been supplied to Brooklyn, Richmond and large areas in The Bronx, Queens and Manhattan. Construction was begun in 1907. In the ten intervening years one of the greatest engineering projects has been completed, New York City's Catskill aqueduct and the first of the artificial storage lakes in the Catskill Mountains,* Ashokan ** reservoir on Esopus *** creek. Night and day the water now flows unceasingly from the mountains to Staten Island, 120 miles. Administrative, legal and physical obstacles have been surmounted. To the City's permanent water resources an addition has been made which can be depended upon for at least 250 million gallons daily in the most prolonged series of dry years likely to occur. Development of the second Catskill watershed, that of Schoharie creek, just being inaugurated, will in a few years round out the system and make the total quantity of new water from the mountains not less than 500 million gallons each day. The City is now using (October, 1917), from all public and private sources, 615 million gallons daily, and has for the past five years been increasing in population at the rate of approximately 157,000 per year, for each added person needing another hundred gallons of water per day.

New York City's Catskill Mountain water-supply system is the greatest of waterworks, modern or ancient, and ranks among the most notable enterprises ever carried out by any city, state or nation. For magnitude and cost and for the variety, complexity and difficulty of physical problems encountered it stands with the great canals, transcontinental railroad systems and New York's own wonderful rapid transit railways. The portion of the great project which has been completed constitutes three-quarters of the whole and embraces the Ashokan reservoir, an artificial lake twelve miles long for storing the waters of Esopus creek, the Catskill aqueduct extending 92 miles from this reservoir to the City's northern boundary and 35 miles within the City limits, including the branch to the Borough of Queens, Kensico storage reservoir near White Plains, Hill View equalizing reservoir at the City line and Silver Lake terminal reservoir on Staten Island.

* Their Indian name was Onteoras, "Hills of the Sky"

** An Indian name signifying "Place of Fish"

*** Another Indian name, meaning "Water"



Map of the Catskill Mountain water system showing its relation to the Croton and Ridgewood systems.

The Greatest Municipal Waterworks

The new Catskill Mountain water supply is a gravity system; that is to say, the water flows without pumping from gathering grounds at a much higher elevation than the City into the distribution pipes under sufficient pressure by the natural force of gravitation. These gathering grounds, from which the water falling as snow and rain flows into definite stream channels, are often called watersheds. Naturally the flow in these streams is very irregular. In periods of flood very large volumes of water rush down their channels, while in dry seasons the same streams could be led through small pipes. As, however, a community needs a steady supply of water, the harvest of the swollen streams must be conserved for use during the periods of deficiency, just as the summer crops of grain are stored in warehouses for use throughout the year. The storehouses, or reservoirs, for the water are natural valleys through which the stream flows, having some narrow part which can be closed by means of a dam, at reasonable expense. Sometimes, besides the main gorge of the stream, there are other low places between hills in the sides of the valley which also have to be closed to the level to which the water is to be raised in the reservoir. This was the case in the part of the valley of the Esopus creek chosen as the site for Ashokan reservoir.

For New York City's Catskill Mountain water system there are two contiguous drainage areas, or watersheds, occupying the central portion of the Catskill Mountains from south to north and lying between 85 and 125 miles from New York's City Hall. The Schoharie watershed is the more northerly, has an area of 314 square miles and drains into the Mohawk river. Esopus watershed slopes toward the south, draining directly into the Hudson river, and has an area of 257 square miles. These two watersheds, therefore, have a total area of 571 square miles, from which it is estimated that, even in an unprecedented series of extraordinarily dry years, more than 500 million gallons of water daily can surely be drawn throughout each year. This area is very sparsely settled. Its rocks are almost wholly sandstones and shales and so the water from this area is of unusual softness and freedom from pollution. Ashokan reservoir, about twelve miles long and one mile wide, stores not only the water of Esopus creek, but a portion of the water of Schoharie creek which will be diverted into it through a tunnel piercing the mountains.

Catskill aqueduct is the great artificial covered channel which leads the water from Ashokan reservoir into the City. Owing to the varied character of country lying between the mountains and the City, the aqueduct is made up of several types of conduit. Some portions are of plain Portland cement concrete built in trenches and covered with earth, known as cut-and-cover; other portions are tunnels through the mountains and hills or beneath the broad, deep valleys; while still other portions are of steel and cast-iron pipes. It is of sufficient capacity to deliver water at the rate of about 600 million gallons daily into the City, so that even if out of service for short periods occasionally for cleaning, inspection or repair, the average rate of delivery will be equivalent to 500 million gallons daily.

Along the aqueduct provisions have been made for storing a large quantity of water near the City in Kensico reservoir; for equalizing the steady draft from Kensico reservoir against the hourly fluctuating demands of the City, by means of Hill View reservoir; for storing a few days' supply on Staten Island as a local safeguard; for improving the quality of the water by aeration, filtration and other means; and for measuring all the water drawn from the reservoirs and sent into the City.

Panorama of Ashokan reservoir from High Point mountain. Esopus creek enters the West basin at extreme left of picture. Between the two basins may be seen Ashokan bridge, the Dividing weir and dike and Upper gate-chamber. Farther to the right is Olive bridge dam.

Silver Lake terminal reservoir, in Silver Lake park, Staten Island, looking south. A fence is to be built around the basins. Later the grounds will be improved by the Park department.

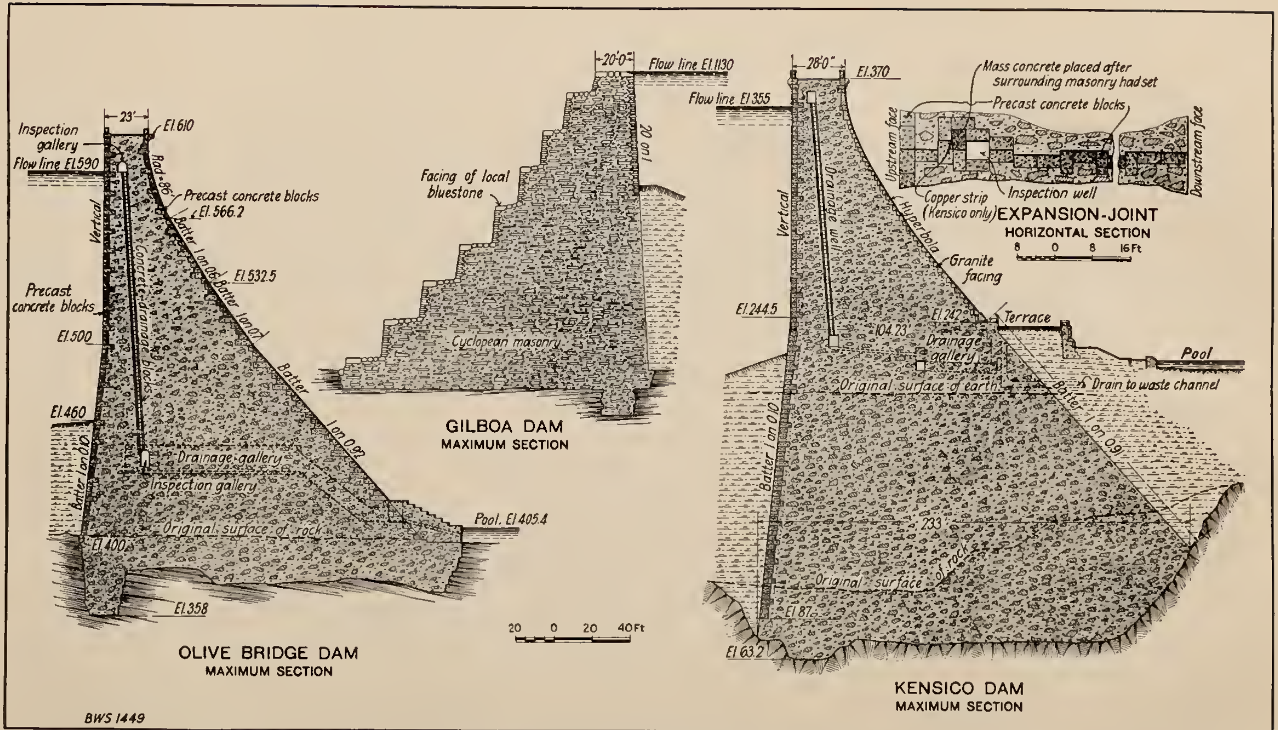
More detailed descriptions of the works are given on the following pages. Many statistical details have been tabulated and the maps, drawings and photographs will aid one unfamiliar with such structures, to comprehend their shapes and sizes, as well as some of the methods used in construction.

From the Ashokan reservoir it is almost a three-days' journey for the water at the average velocity to flow through the aqueduct to the Silver Lake terminal reservoir on Staten Island, in the course of which it flows along many a steep hillside, crosses several broad plains, pierces mountains, descends beneath rivers and wide, deep valleys, traverses the Boroughs of The Bronx, Manhattan and Brooklyn, and crosses the Narrows of New York harbor.

THE PREPARATION

Preceding the active period of construction which has been crowned by the City's achievement was a long period of preparation. Passing over informal suggestions for increasing the water supply appearing from time to time, the campaign may be said to have opened in earnest with a report presented March 15, 1897, to the Manufacturers' Association, of Brooklyn, by a special committee, of which Charles N. Chadwick was chairman, appointed November 2, 1896, which had investigated the problem broadly because of that community's frequently recurring need for more water. Four recommendations were made in this report: That all plans for water should contemplate a Greater New York; that to finance the project the State constitution must be amended to separate water debt from the constitutional debt limit; that the project should be administered by a commission in charge of the work from start to finish; and that the City's needs for a period of fifty years should be considered. In 1901, following the agitation by this association, a bill was introduced by it in the legislature, having for its object the creation of a commission empowered to add to the water supply of the City, and, failing of passage, similar bills were introduced successively in 1902, 1903 and 1904. Old New York City was also reaching the limits of its supplies.

In 1898, the consolidation of the municipalities around the harbor, within New York State, was consummated, uniting in one city a population of 3,250,000. Soon afterwards a private corporation proposed to supply the City from the Ramapo river and the Catskill mountains on terms which should have been very profitable to the private corporation. This attempted exploitation of the City's need led Comptroller Bird S. Coler to have a thoroughgoing investigation made by disinterested engineers, under John R. Freeman, whose report in 1900 set forth many important facts about the City's existing water systems, its use and waste of water, the need for additional supplies and certain sources from which additional water might be obtained. The Ramapo scheme was exposed and the community aroused. Civic organizations became active, especially the Merchants' Association, which engaged a number of engineers to conduct independent investigations, whose reports were published in one large volume under date of August, 1900. By special agreement with the Department of Water Supply, Gas and Electricity, in December, 1902, William H. Burr, Rudolph Hering and John R. Freeman were engaged as a Commission on Additional Water Supply to make an exhaustive investigation of the needs of the various boroughs of the City for water, means for curtailing waste, the most available sources of supply and the best means of



Cross-sections of the principal masonry dams of the Catskill Mountain waterworks. Flood waters will flow over the top of the Gilboa dam but not over Olive Bridge nor Kensico dam.

procuring a suitable increment. A large, well-organized engineering and accounting staff was employed, and after a year of hard work, a voluminous report was submitted to Water Commissioner Robert Grier Monroe which contained definite plans in detail for improving existing works and for making progressive additions from sources both east and west of the Hudson river. Laws enacted by the next legislature prohibited the City from utilizing most of the sources east of the Hudson. The Hudson itself had been proven by the commission to be unsuitable. Meanwhile efforts were being put forth to get as much more water as practicable from the Croton river and Brooklyn's wells in Nassau county.

Thus might the situation be summarized at the end of 1904. Ten years had been spent in gathering information and educating the people and the State and City governments. One very important preparatory step had been taken: in 1904 an amendment to the State constitution had been ratified removing capital expenditures for waterworks from the municipal debt limit. Meanwhile the population of the greater City had increased to 4,000,000 and was growing at the rate of 115,000 per year. Demands for water were rapidly outstripping the supplies available and severe shortage had barely been escaped on more than one occasion. Amid these conditions the City again appealed to the legislature at the beginning of 1905 and the McClellan bill was introduced. After some vicissitudes, having the combined backing of the City administration and the civic associations, this bill became a law by the signature of Governor Higgins, June 3, 1905.

To safeguard the interests of all communities in the State and control the utilization of all the State's water resources, the legislature passed coincidentally another bill creating a State Water Supply Commission. These bills became respectively Chapter 724 and Chapter 723 of the Laws of 1905. Subsequently these laws were amended and other general and special legislation enacted which affected the City's water project, as the years passed. The State Water Supply Commission was abolished and its duties assigned to the State Conservation Commission. New York City was required to create and maintain a special constabulary for the protection of the communities in which its great construction work was to be carried on. Certain municipalities were given rights to take water from the new aqueduct. Labor laws were made more drastic. The workmen's compensation act was passed. Methods of acquiring and paying for real estate were narrowly defined. Payment for indirect damages to lands not taken, and for loss of business and wages was provided for. The Public Health Law was amended to aid in the sanitary protection of the City's sources of water supply, but not effectively. Thus the rules by which the work must be conducted were laid down.

NEW YORK'S WATER SUPPLIES PRIOR TO 1917

Other than wells, with hand pumps, the first municipal waterworks within the limits of New York City were those for the lower part of Manhattan Island, which, commencing in 1776, with a population of 25,000, was supplied with well water pumped by a steam engine into a reservoir near Pearl street and Broadway and distributed through pipes made by boring logs. These works were soon abandoned on account of the Revolution, but a similar service was furnished after 1800 by the Manhattan Company and in 1830 by the town, when the population had reached 200,000. These early supplies were never satisfactory as to either quantity or quality. About this time, following an epidemic of yellow fever, a new source of supply was sought and many possibilities were considered, includ-

Downstream face of the masonry portion of Olive Bridge dam, from a point in the gorge. Note the rocky bed of Esopus creek and the low, rustic stone dam holding the water in the pool at the toe of the large dam.

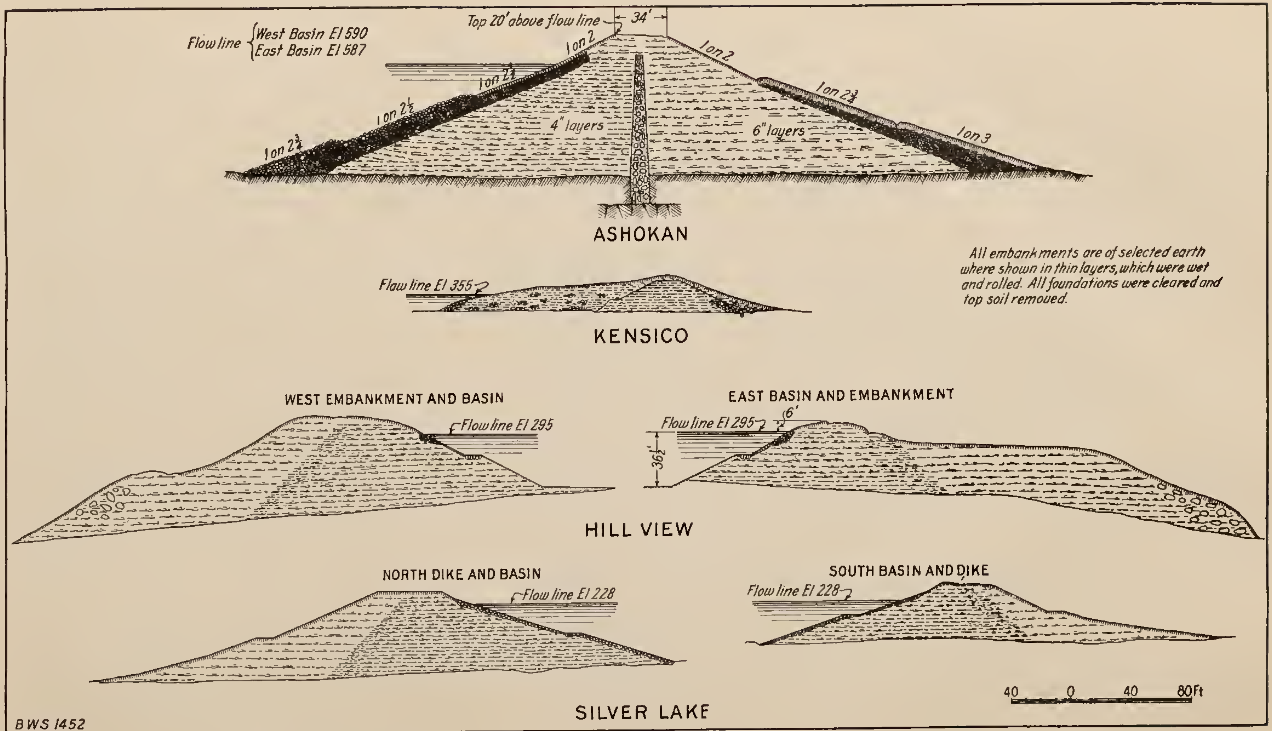
ing the Hudson, Passaic, Bronx and Croton rivers. Commissions appointed in 1833 and 1834 recommended the utilization of the Croton river and the next year this choice was ratified by popular vote. Surveys and plans were soon commenced. Construction of the Old Croton aqueduct was begun in 1837 and sufficiently advanced in 1842 to supply water to the Murray Hill distributing reservoir on the site of the present Public Library at Fifth avenue and 42nd street.

A diverting dam was built across the Croton river at a point 38 miles, in air line, from the City Hall and an aqueduct 34 miles long, of 80 million gallons daily capacity, built along the slopes of the hills on the eastern side of the Hudson river to Yonkers, where it turned inland and passed southward through The Bronx to the Harlem river, which it crossed upon the High Bridge. Another distributing reservoir was built within the area that is now Central Park, between 79th and 86th streets.

Within a generation the original Croton works were outgrown. Additional impounding reservoirs were constructed upon branches of the Croton river from time to time to conserve more of the water which had been running to waste over the Croton dam. Severe droughts in 1880 and 1881 forced attention upon the water question and proved the inadequacy of the supply and the need of additional works. A Board of Aqueduct Commissioners was established in 1883, pursuant to special legislation, and construction of the New Croton aqueduct was begun two years later. The first water passed through the new aqueduct in July, 1890, and it was put into regular service the following year. Of tunnel construction, its route is a nearly straight line from the Old Croton dam to Jerome Park reservoir. Its length is 31 miles to its terminus at the 135th Street gate-house, whence lines of 48-inch cast-iron pipe were laid to a new distributing reservoir constructed in Central Park between 86th and 96th streets, and to other points for delivery of water. The rated capacity of the New Croton aqueduct is 300 million gallons daily. June 1, 1910, the Aqueduct Commission went out of existence, the development of Croton watershed having been completed, by the completion of the New Croton reservoir with its great dam three and a half miles above the point of discharge of the Croton river into the Hudson and several other notable reservoirs. The Croton system as completed embraces the two aqueducts, ten reservoirs and six controlled natural lakes, making the total storage 104 billion gallons. As thus developed, the Croton river will yield, even in periods of drought, a daily supply of 336 million gallons.

The Borough of The Bronx, formerly known as the annexed district, when made a part of New York City, shared its Croton water. In 1884, however, a separate additional supply for the Williamsbridge district was obtained from the Bronx river, and in 1897, the water of the Byram river also was taken. These two streams are situated in southeastern Westchester county, and together supplied about 18 million gallons daily through Lake Kensico, from which a 48-inch cast-iron pipe led to the Williamsbridge distributing reservoir.

Brooklyn, having nearby the water-bearing sands characteristic of the southerly slopes of Long Island, naturally obtained its public and private supplies of water therefrom. Like old New York City, Brooklyn did not develop a public water supply until its population had approached 300,000, depending upon private sources until 1859. These public sources of supply were developed principally by means of groups of wells and pumping stations, although in the early years of the 20th century the wells were supplemented by two large infiltration galleries. Ultimately an area of 168 square miles was utilized by means of the underground



Cross-sections of earth dams, or dikes, of the various Catskill Moun tain water supply reservoirs.

works and eleven supply ponds. The wells are of both shallow and deep types and were capable of yielding 60 million gallons daily, while the infiltration galleries could supply an additional 40 million gallons. The total maximum dependable yield of this source was 150 million gallons daily. The water thus collected was conveyed into the City through a brick conduit and large cast-iron and steel pipe-lines. Pumping-stations and distributing reservoirs within the City completed the Ridgewood system, as it is sometimes called. All this water had to be pumped at least twice and some of it four times, at great expense.

Queens and Richmond (the latter being Staten Island), the two remaining boroughs of Greater New York, were supplied from local wells developed and owned by private water companies. Parts of Brooklyn also were supplied by private companies. Some of these works have been bought by the City.

In quality, the water obtained for the five boroughs from most of these sources was satisfactory until the sources were overworked in endeavors to meet the rapidly increasing demands of the City caused by its phenomenal growth in population and the wonderful development of its commerce and industries. Very briefly, this is the outline of the public water systems of the several communities now constituting Greater New York up to the introduction of Catskill water in 1917.

THE BOARD OF WATER SUPPLY—ITS FUNCTIONS AND ORGANIZATION

Chapter 724 of the Laws of 1905 provided for "An additional supply of pure and wholesome water for the City of New York; and for the acquisition of lands or interest therein and for the construction of the necessary reservoirs, dams, aqueducts, filters and other appurtenances for that purpose; and for the appointment of a commission with powers and duties necessary and proper to attain these objects."

The three commissioners were appointable by the Mayor and removable only "for incompetency, or misconduct shown after a hearing, upon due notice, upon stated charges," thus assuring continuity of administration and policy in the general direction of the work. As stipulated in the law, the duties of the Board were "to proceed immediately and with all reasonable speed, to ascertain what sources exist and are most available, desirable and best for an additional supply of pure and wholesome water for the City of New York," to make the necessary surveys and investigations, to prepare maps, plans, estimates and contracts; to acquire real estate and other rights and to construct the works determined upon with the approval of the Board of Estimate and Apportionment and the State Water Supply Commission.

For the performance of these duties the Board was empowered to select its officers and its engineering, clerical and other staffs, to enter into contracts and in addition to powers specifically conferred, to have "such further powers as may be requisite to the efficient performance of the duties imposed upon it."

June 9, 1905, Mayor McClellan appointed from three lists of three names each submitted by the Chamber of Commerce of the State of New York, the Manufacturers' Association of New York, with headquarters in Brooklyn, and the Board of Fire Underwriters, respectively, J. Edward Simmons, who was elected president, Charles N. Chadwick and Charles A. Shaw. The vacancy caused by the resignation of Mr. Simmons was filled by the appointment by Mayor McClellan of John A. Bensel, who was elected president January 31, 1908.

Olive bridge dam, showing methods of construction. Four steel cableways suspended between towers spanned the valley and delivered materials, while stiff-leg derricks placed the stones and concrete in the dam. In the background are the concrete mixing plant and the yard where the concrete facing blocks were cast.

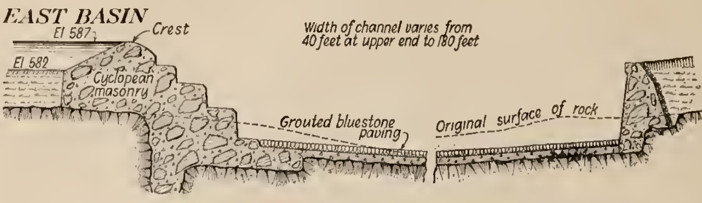
His resignation at the close of 1910 was ~~followed~~ by the appointment by Mayor William J. Gaynor of Charles Strauss, who was elected president, February 7, 1911. Mr. Shaw resigned January 12. 1911, and his place was filled by the appointment of John F. Galvin, January 23, 1911. The present commissioners, therefore, are Charles Strauss, President, Charles N. Chadwick and John F. Galvin.

By the law creating the Board of Water Supply the Corporation Counsel of the City of New York was made its attorney at law and legal adviser. Similarly, the Comptroller of the City was authorized and directed to raise from time to time by the issuance of corporate stock of the City, such sums of money as would be required to defray the Board's financial obligations and to make payments upon vouchers properly prepared by the Board. Thus in effect, the Comptroller became the disbursing officer of the project.

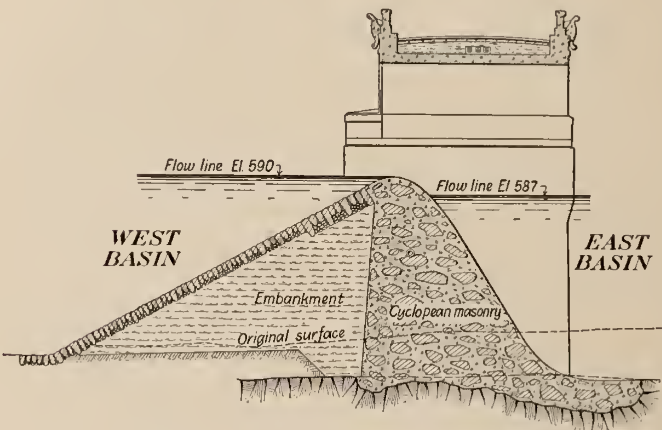
During the summer of 1905, John R. Freeman was appointed Consulting Engineer to the Board and J. Waldo Smith, Chief Engineer. There were also appointed during the summer consulting engineers and numerous other members of the Chief Engineer's staff. Organization and equipment of the forces were begun August 1. With the cordial co-operation of the Municipal Civil Service Commission, the large force needed was secured as the requirements of the work dictated. Great care was exercised in the selection of all employees, and particularly of the leaders of the various units. Development of the work through the successive stages of preliminary organization and investigations, surveys and location, preparation of designs and contracts, construction, equipment, tests and trial operation, necessitated corresponding adaptations of the force. Flexibility was therefore an important element in the scheme of organization. By law the Board was required to do practically all the construction by contracts based on bids received after public advertisement. Consequently no large labor forces were employed directly by it.

To follow all the adjustments of the force would be wearisome. The scheme of organization, however, is of interest and can best be set forth by an outline of the maximum force. The Board's chief functions were distributed to bureaus, the heads of which reported directly to the Commissioners, each bureau being divided and sub-divided according to the character of its assignment. The Administration bureau was headed by the secretary and had charge of the official records, accounts. the purchasing of supplies and of other matters of general administration. The Real Estate bureau was charged with the acquisition of property by direct purchase, the adjustment and payment of taxes on property acquired by the Board, the temporary rental of some of the property acquired, and miscellaneous matters affecting the Board's real estate. The acquisition of the great areas of land required for the reservoirs and the aqueduct by condemnation proceedings was in general put by the law into the hands of the Supreme Court through the appointment of commissioners of appraisal. In these proceedings the Board was represented by the Corporation Counsel and special counsel appointed by him.

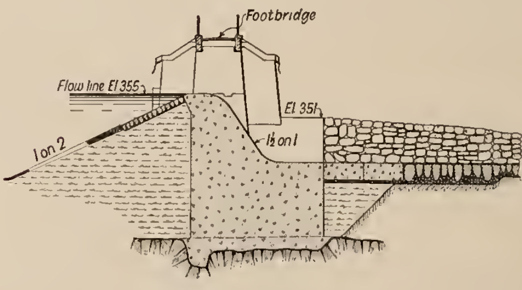
To the Police bureau was assigned the patrolling of the labor camps of the contractors and the protecting of "the inhabitants of the localities in which any work may be constructed under the authority of this act and during the period of construction, against the acts or omissions of persons employed on such works or found in the neighborhood thereof." Upon the Bureau of Claims was laid the duty of collecting facts relating to claims for indirect damages to real estate not taken by the Board but affected by its operations, claims for damages to



ASHOKAN WASTE WEIR AND SPILLWAY
Crest length 990ft.



ASHOKAN DIVIDING WEIR AND BRIDGE
Crest length 1000ft



KENSICO WASTE WEIR
Maximum section
Crest length 50ft

0 2 6 10 14 18 22 Ft

BWS 1451

established business arising from the creation of the new water system, and corresponding claims for loss of employment. This bureau keeps records of all such claims and co-operates with the Corporation Counsel in their investigation and in defense of the City in proceedings before commissioners of appraisal and in courts.

The largest of all the bureaus from the very nature of the enterprise has always been the Engineering bureau, headed by the Chief Engineer. To this bureau has been committed the making of surveys and investigations, the preparation of maps, plans, estimates, designs, contracts and reports, the selection, inspection and test of supplies, equipment and materials, the supervision of construction and the up-keep and operation of the works as completed until turned over to the Department of Water Supply, Gas and Electricity for regular service. The great variety of this bureau's functions and the geographical extent of the territory occupied necessitated a complex but well-articulated organization. As his immediate aides the Chief Engineer had a small personal staff, a deputy chief engineer, three consulting engineers, and as required from time to time experts in various specialties. The bureau was divided into departments and sub-divided into divisions and sections with department, division and section engineers in charge, the department engineers reporting directly to the Chief Engineer.

Headquarters department was charged with the preparation of real estate maps and descriptions, the design of all the structures and equipment, both engineering and architectural, and investigations leading thereto; the inspection of all manufactured materials, supplies and equipment, the selection, storing and distribution of the supplies and equipment used by all departments of the Engineering bureau; all Civil Service matters for the bureau and miscellaneous administrative duties, and the preliminary surveys and investigations for the tunnel and conduits within the City limits. The other departments were field departments, and their duties were geographically limited. Within its limits each department had charge of surveys, supervision of construction, and ultimately of the up-keep and temporary operation of the completed works. Sub-division of these field departments also was determined largely by geographical considerations, although affected by the character of the departments. In each department, however, there was an executive division having charge of administrative matters and serving as the personal staff of the Department Engineer. In round figures, the value of the work assigned to each field department approximated $30,000,000. Reservoir department had charge of all work on the watersheds and the headworks of the Catskill aqueduct. Northern Aqueduct department was in charge from the headworks to the westerly boundary of the Croton watershed; Southern Aqueduct department from the latter point to the City line; and the City Aqueduct department had charge of all work within the City limits from the beginning of the period of its active construction. One other field department, known as the Long Island department, existed temporarily for the investigation of the underground water supplies of Suffolk county and the preparation of a scheme for the utilization of these sources. This department was disbanded after the completion of a comprehensive detailed report, when it was found that the legal obstacles preventing the City's utilization of these waters could not be overcome.

With one or two exceptions, each department had four to six divisions, each field division having supervision of construction work amounting in value to about $5,000,000 to $9,000,000, under the general direction of the department engineer. Each field division was subdivided into four to six sections, according to the char-

Ashokan reservoir, showing portions of the Beaverkill and Dividing dikes, the Lower and Upper gate-chambers, Ashokan bridge, and the Dividing weir under the bridge. The East basin is in the background.

acter of the structures and the nature of the country, each section engineer being assigned such an amount of work as he could constantly give personal supervision. Divisions of Headquarters department and the executive divisions and sections of field departments were given commensurate responsibilities according to the volume and nature of the duties to be done.

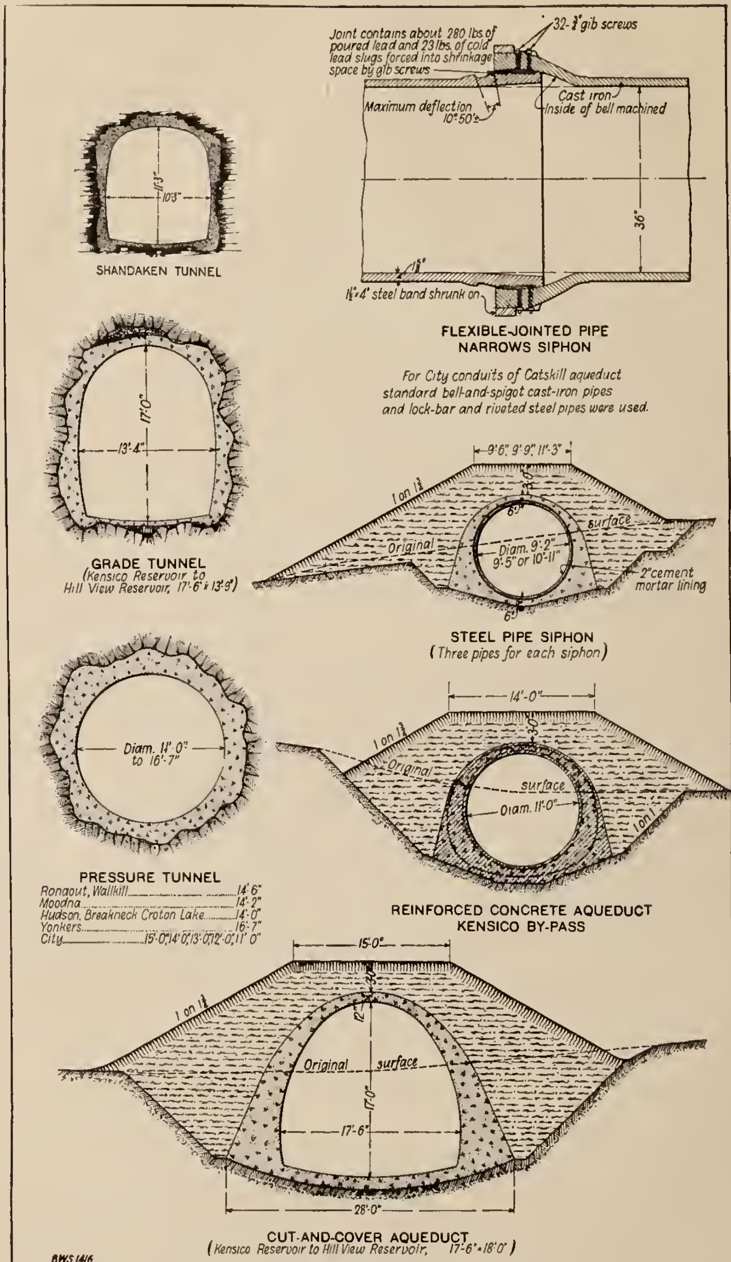
Welfare and Sanitation

Welfare work for the forces of the Board and its contractors received constant attention. A small special corps of sanitarians was employed by the Board to supervise the location, construction, drainage and upkeep of all labor camps, to inspect all water and food supplied for laborers and mechanics resident in the camps, to see that communicable diseases were prevented, or patients removed or suitably treated, and that in general the camps were kept in a healthful and orderly condition. Each contractor was required to maintain competent camp physicians and nurses and adequate hospitals, and to examine all employees before admitting them to camp. So far as practicable, camps were located outside the limits of watersheds used by the City or any other community as sources of water supply. Where camps on watersheds used as sources of supply could not be avoided, great precautions were taken to prevent contamination, by means of purification works for wastes and vigilant patrol. With few exceptions, even in camps outside watersheds, all garbage and excreta were incinerated and drainage chemically treated or filtered or otherwise disposed of so as to cause no harm or nuisance.

To make life more agreeable for the men in camp and help them to self-betterment, especially in the larger camps, evening schools, clubs, amusements, Young Men's Christian Association quarters and other facilities were provided. In some instances prizes were offered for the best garden, or day schools were maintained for the children, or a post-office or a bank was established. Most camps had general stores, or commissaries. Usually camps were on lands provided by the City and undesirable camp followers and intoxicating liquors excluded. Little trouble arose in any of the regular camps. Such troubles as did occur were chiefly in the "outside" camps, over which neither the City nor its contractors had any control, on land rented from local citizens whose desire for profit overcame their sense of morality and public decency.

A most commendable record was made for orderliness, healthfulness and freedom from labor troubles. No epidemic occurred among the laborers nor in any of the communities in which laborers connected with the work were quartered, or in communities on whose watersheds camps were situated. These excellent results are attributable to the requirements of the Board's contracts and to the faithfulness with which sanitary and police regulations were carried out by the contractors and the Board's forces.

In all contracts requiring work on watersheds used by communities or along the aqueduct, sanitary clauses were inserted to the end that the health of employees, of local communities, and of the people using the water from the drainage areas affected by the construction operations, would be safeguarded. Employees violating sanitary rules were summarily dismissed and not again employed. Ample supplies of wholesome water were insisted upon, as well as good food, and sanitary conditions generally. As administered, the sanitary precautions proved effective. The death rate, exclusive of accidents, averaged only about 3.5 per thousand in the camps.



Standard types of conduit used in the Catskill aqueduct. (In addition to the above, riveted and lock-bar joint steel pipes and bell-and-spigot cast-iron pipes of ordinary types were used.)

As results of this attention to the human side of the construction forces and of the influence of the camp schools, in which the men were instructed in the English language and given information about American institutions, a better class of laborers was secured and *there were no strikes.*

Schoharie Water

When the second stage of the Catskill Mountain water-supply project was outlined in 1905, it was anticipated that the water needed to supplement that of Esopus creek in order to fill the Catskill aqueduct, would be obtained partly from the Rondout and partly from the Schoharie creeks. While the work in the Esopus valley was proceeding, topographical surveys and borings of possible dam sites in the Rondout and Schoharie valleys were carried on. After extensive boring operations, it was conclusively determined that no favorable sites for dams could be found on the Rondout creek. Meanwhile, investigations on Schoharie creek led to the abandonment of one dam site after another, following downstream, until finally a very satisfactory site was found at the Village of Gilboa. With an economical dam and reservoir at this location, owing to the increased watershed available, it was found that all the water needed could be obtained from Schoharie creek alone and so the utilization of the Rondout creek was given up.

The Schoharie creek flows northward into the Mohawk river; therefore, its water must be turned southward into the Esopus creek and Ashokan reservoir in order to get it into the Catskill aqueduct. Between the two valleys lie the broad, rugged Shandaken ranges of the Catskill mountains. A tunnel, therefore, is necessary and it will be the longest tunnel for any purpose in the world so far as known, its total length being a little over 18 miles from inlet to outlet. The reservoir will be principally a diverting basin, as about two-fifths of the storage capacity of the Ashokan reservoir was intended for the water from Schoharie creek. Consequently, Schoharie reservoir will have a capacity of only 22,000,000,000 gallons. Its surface, when full, will be 1,130 feet above tide-water in New York harbor, and 540 feet above the surface of Ashokan reservoir. The water from the tunnel will be discharged into Esopus creek at the Village of Allaben and will flow for about 11 miles in the Esopus creek channel to the westerly end of the Ashokan reservoir.

Water by Gravity

One of the great advantages of the new supply of water from the Catskill mountains is that the reservoirs in the mountains are at such elevations that the water can flow by gravity to the City and be delivered within its limits into the street mains at such pressures that it will rise to the hights necessary for service in practically all parts of the City and in buildings of all reasonable hights, without pumping. The pumping rendered unnecessary by this high gravity pressure of the Catskill water has cost the City and property owners large sums of money. Of course, this cost cannot be exactly stated, but it has been roughly estimated for recent years at $2,000,000 per annum. Not only is the expense saved, but the tens of thousands of tons of coal required each year can be conserved for other purposes and mechanics needed in pumping plants liberated for employment elsewhere. Such small amounts of power as are needed for operating aqueduct equipment and lighting some of the structures is either generated by the fall of the water drawn from the reservoir into the aqueduct, as at Ashokan reservoir, or obtained from an electric power company in exchange for the use of portions of the aqueduct

A group of highway bridges, all of reinforced concrete. (1) Esopus bridge across the creek just above the westerly end of the reservoir. Five spans, 67½ feet. (3 and 5) Spillway bridge, 175-foot span, across the Waste channel through which flood waters are discharged which pass over the Waste weir of Ashokan reservoir. (2) Traver Hollow bridge over a small stream entering the West Basin of Ashokan reservoir, a 200-foot, 3-hinged arch. (4) Ashokan bridge crossing the reservoir between the East and West Basins, 15 spans of 67½ feet. (6) Rye outlet bridge across Kensico reservoir, 5 spans of 127 feet.

lands, for the part of the aqueduct south of Putnam county. A gravity system, requiring but few men for its operation, and the large majority of them "unskilled," is but little affected by the rise of wages, in comparison with works employing large numbers of mechanics.

The Cost

For surveys, real estate, construction, engineering and general supervision, and all other items except interest on the bonds, the total cost of the completed Catskill system will be about $177,000,000, of which $22,000,000 are for the Schoharie works. To October, 1917, $139,000,000 have been expended.

Some Comparisons

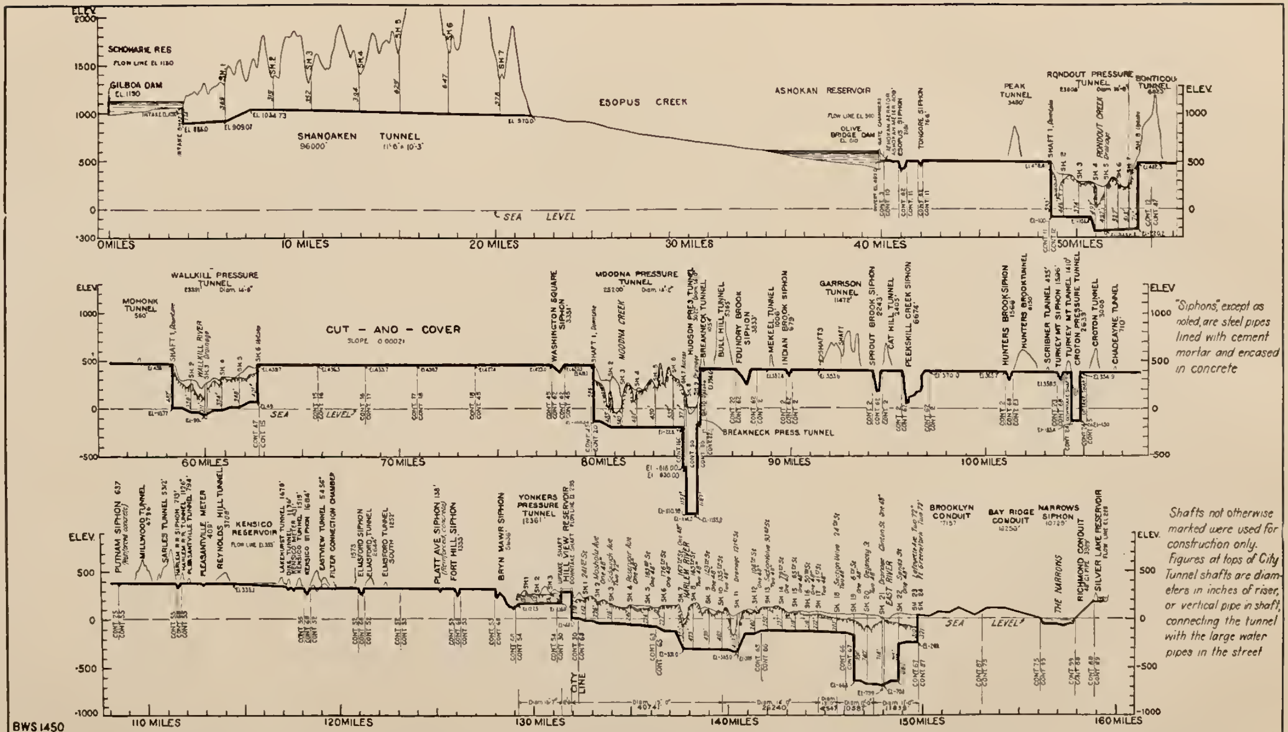
The magnitude of New York's new waterworks and of the problem of supplying the metropolis with water will be more comprehensible from a few comparisons. To state the growth in population in bare figures suggests but little. Instead it may be written that each year New York adds people enough to make an Atlanta, a Hartford, a Memphis or a New Haven; or every three years a Buffalo, a Cincinnati or a San Francisco; or in four years, a Baltimore or a Pittsburgh, or enough to populate the State of Rhode Island. From the beginning of the official steps toward an additional water supply to the completion of the first installment of the Catskill Mountain system, the increase of New York's population is more than the present population of Chicago, or as much as the combined populations of Philadelphia and Detroit.

Ashokan reservoir can hold nearly as much water as all the ten reservoirs of the Croton system and Kensico reservoir combined. All the Catskill reservoirs together hold nearly twice as much as the ten Croton reservoirs. Their contents would fill the North river from the Battery to Hastings.

The cut-and-cover aqueduct and the tunnels are more than big enough for railroad trains to pass through them with ease. Catskill aqueduct is twice as long as the two Croton aqueducts put end to end. The water which the Catskill aqueduct can carry would be waist deep between the buildings in Fifth Avenue's fashionable shopping district, if flowing at a comfortable walking speed. The water used by New York City each day weighs about eight times as much as its population.

The two deepest shafts of the City tunnel of the Catskill aqueduct, one at the corner of Clinton and South streets, and the other at the corner of Delancey and Eldridge streets, Manhattan, are each as deep as the tower of the Woolworth Building is high. If the Eiffel Tower could be stood with its foundations in the Hudson River tunnel, its top would not appear above the river surface, or if two Woolworth Buildings were stood one on top of the other, the lower one having its foundations in the Hudson River tunnel, the top of the upper one would just reach the level at which the water flows away through the mountain on the east bank of the Hudson after rising in the shafts from the tunnel beneath the river.

Persons frequently ask whether Croton water can be put into the Catskill aqueduct or Catskill water into the Croton system. Catskill water is delivered into Hill View reservoir at the City line at a level 295 feet above tide, while Croton water is delivered into Jerome Park reservoir 134 feet above tide, or 161 feet lower. It is evident, therefore, that Croton water could be put into the Catskill system when the latter is in service only by pumping to overcome this



Profile of Catskill Mountain water supply system from Gilboa dam to Silver Lake terminal reservoir, showing the elevations of the reservoirs and of the different parts of the aqueduct.

difference of level. Catskill water can, however, by wasting this advantage of level, be turned into the Croton reservoir, which is crossed by the Catskill aqueduct, into the Croton system at Jerome Park reservoir, or at the 135th Street gate-house. If the Catskill aqueduct should be out of service, Croton water could be admitted to the City tunnel and conduits and delivered to any of the boroughs, but of course only at the lower pressure of the Croton system.

THE FUTURE

If New York City continues to increase in population and to use water at the same or a greater rate per person, it is, of course, a question of simple mathematics to compute the date when the City's demand for water will have outstripped the capacities of its present water systems and of the new sources in the Catskill mountains now provided for it. Conservation of the supplies through metering and other means for reducing waste and extravagant use may postpone the date when the City must once more undertake the extension of its water system. Where the next supply can be obtained cannot now be safely predicted. Possibly the legal obstacles which bar the City from Suffolk county can be removed, and, similarly, water physically obtainable at moderate cost in Connecticut and Massachusetts might be made available through the overcoming of inter-state restrictions. Difficulties in the Rondout valley might be surmounted, and the Catskill Creek water, although of less satisfactory quality and expensive to obtain, may become the most feasible supply at some date. Beyond these are the waters of the upper Hudson in the Adirondack mountains, to which people so frequently advert without appreciation of the cost of developing and conveying these waters to New York City. While the City continues to grow, its water-supply problems will recur for solution from time to time. It is important that vigilance should be exercised to maintain the quality of all the present supplies by protecting them from pollution and treating them by approved modern methods, and that the structures should be kept constantly in good repair.

The Catskill aqueduct has interlinked the earlier systems of water supply and the distribution systems of all the five boroughs as they have never been before. This makes possible not only the utilization of water from any source in any part of the City, but since the Catskill, the Croton and the Ridgewood systems can now be operated in conjunction, the effective safe capacity of the combined systems is greater than the sum of the several capacities of the three if wholly disconnected. Hence the Catskill system not only supplements the permanent great systems which preceded it, but enhances their value to the City.

DETAILED DESCRIPTION OF THE NEW WORKS

Ashokan Reservoir

Ashokan reservoir, about 14 miles west of the Hudson at Kingston, was built under contracts amounting, together with the expense for relocating highways and the Ulster and Delaware railroad, to nearly $20,000,000. The water which this reservoir holds would cover all Manhattan Island to a depth of 30 feet; the area of its surface is equivalent to that of Manhattan below 110th street. Olive Bridge dam, across Esopus creek; the Beaver Kill and Hurley dikes, or earth dams, across smaller streams and gaps between the hills forming the natural walls of the reservoir; the Dividing dike and weir dividing the reservoir into two basins,

CONTRACTORS' CAMPS—(1) Outdoor stoves at Camp Hill View. (2) Chadwick avenue at "Camp City" at Ashokan. (3) Mess hall, Camp Hill View. (4) Camp Blakeslee near Croton lake, now completely obliterated. (5) Operating room in contractors' hospital. (6) Recreation at close of legal 8-hour day.

and the Waste weir over which the surplus flood waters may safely be discharged, are the principal structures of this reservoir.

The water surface of the West basin when full is at an elevation of 590 feet above mean tide in New York harbor, which is also the elevation of the crest of the dividing weir over which the water flows into the East basin. The level of the East basin, when full, is 3 feet lower than that of the West basin and from it flood waters overflow through the spillway and a brook channel into Esopus creek about two miles below Olive Bridge dam. Water can also be drawn from one basin into the other through a gate-chamber in the dividing weir which contains four sluice gates, each 5 feet by 15 feet.

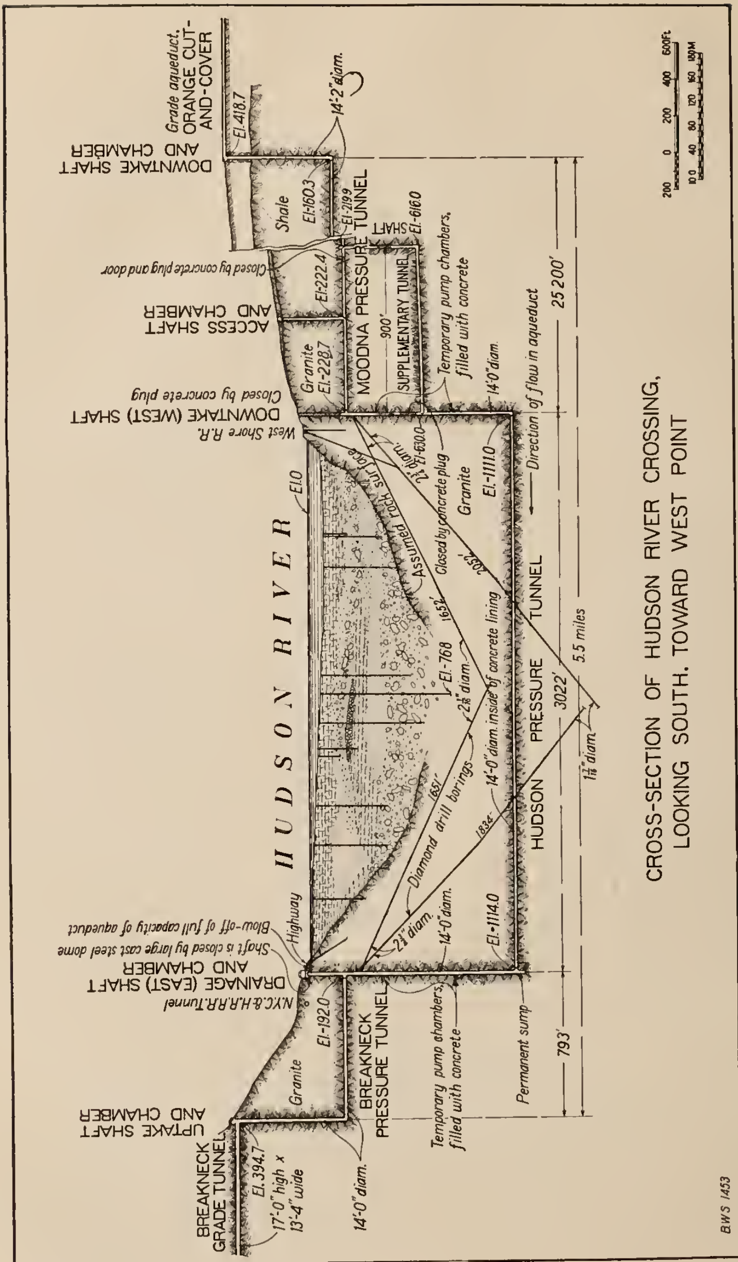
Olive Bridge dam is a massive structure consisting of a central masonry portion 1,000 feet long extended by earth dikes, or embankments, known as the North and South wings. The masonry part, founded on solid ledge-rock, is built of cyclopean concrete with pre-cast concrete face blocks. The wings of the Olive Bridge dam and the dikes are built of selected earth spread in layers 4 or 6 inches thick and compacted by heavy rollers. Each dike has a concrete core-wall extending to ledge-rock or into very compact impervious earth foundation, often called hardpan.

The bottoms and slopes of the reservoir basins were cleared of trees, brush, buildings and other objectionable things. Around the reservoir new highways, aggregating about 40 miles in length, requiring the construction of 10 new bridges, all of reinforced concrete, have been substituted for the submerged roads. One of these bridges, at Traver Hollow, is a 3-hinged arch of 200-foot span, and Ashokan bridge, crossing the reservoir on the Dividing weir, is 1,120 feet long and has 15 arches of 67.5-foot span.

In order to keep population at a reasonable distance from the shores of the reservoir and thus protect the waters from immediate pollution, sufficient area of land was taken to afford a marginal strip at least 1,000 feet wide all around the shore. The relocated highways in the main were placed on the boundaries of these lands. The lands are also fenced, the intention being to keep the public away from the water so far as practicable.

Construction camps and equipment.—The work on the dam, the dikes, the highways and other structures at Ashokan reservoir required an army of laborers, mechanics and foremen which attained a maximum of 3,000 men, who lived, many of them with their families, in a camp built by the contractors near the work. The camp was divided into Italian and Negro sections, while white Americans lived separately. There were provided sewerage and water-supply systems, a special plant for the disposal of sewage, good dwellings, generally one-story wooden structures with screens on all doors and windows, well-laid-out streets, electric lights, telephones, national and savings banks, hospital, general store, bakery, police, fire protection, a kindergarten and schools for children, churches, Young Men's Christian Association and a post-office. The maximum population was approximately 4,500. An evening school for men was one of the features of the camp. Besides the Camp City, there were other smaller camps on outlying parts of the work. Upon the completion of work, these camps were so thoroughly obliterated that scarce a trace can now be found.

For constructing Ashokan reservoir, the contractors assembled approximately 30 miles of railroad, 33 locomotives, 579 cars, 60 derricks, 7 cableways, 16 steam rollers, 19 steam shovels, a steel trestle bridge 390 feet long and 85 feet high, air-



CROSS-SECTION OF HUDSON RIVER CROSSING, LOOKING SOUTH. TOWARD WEST POINT

compressors, stone crushers, concrete mixers, etc., costing much more than a million dollars. Quarries were opened in the nearby hills to obtain stone, and several hills of clayey earth were partially dug away to build the earth dams.

Kensico Reservoir

Kensico reservoir, east of the Hudson, and 30 miles from the City Hall, contains enough Catskill water to supply New York several months if carefully husbanded. It acts as a storage reservoir, so that the flow into the City will not be interrupted while the 75 miles of aqueduct between it and Ashokan reservoir are being inspected, cleaned or repaired at any time. This reservoir is formed by the Kensico dam across the valley of the Bronx river, about three miles north of White Plains and 15 miles north of the Hill View reservoir. One mile northwest from the Kensico dam, a shallow gap in the hills was filled with an earth dike about 1,450 feet long, with a maximum hight of 25 feet. The water is 110 feet deep over the surface of the old Kensico reservoir, which was developed in 1885, and 54 feet deep over the surface of the Rye ponds, which were auxiliary to the old Kensico reservoir and are included in the new.

For the new Kensico reservoir, 3,200 acres of land were acquired; which, in addition to the 1,300 acres acquired for the old reservoir and Rye ponds, make a total of 4,500 acres, providing a marginal protective strip around the entire flow line in but few places less than 500 feet wide.

Catskill water is delivered into Kensico reservoir at the upper end of the Bronx valley where the hydraulic grade line of Catskill aqueduct coincides with the normal surface of the reservoir, Elevation 355. At this place there is a covered influent weir and a gate-house. The water is drawn from the reservoir through a short tunnel at a point on the west side of the reservoir about one mile above the Kensico dam. At the reservoir end of this tunnel is the Upper Effluent gate-house containing sluice-gates for controlling the flow from the reservoir into the aqueduct. At the lower end of the outlet tunnel is a large gate-chamber in which the flow of the water is regulated by valves and either diverted through the Kensico aerator or sent directly to the aqueduct. Near the Lower gate-house is the screen chamber in which all the water is passed through fine mesh screens before it flows on toward Hill View reservoir. A reinforced concrete by-pass conduit, 11 feet in diameter and 11,000 feet long, from the Influent gate-house at the upper end of the reservoir, connects with the Upper Effluent gate-house so that water may be delivered directly through the aqueduct without sojourning in the reservoir.

Although the Kensico reservoir is within 15 miles of the City line, it lies in a practically undeveloped region, consisting principally of farms and woodland, with no important industry. New highways were required, the most important of which is the county road leading from White Plains to Mount Kisco. This crosses an arm of the reservoir on a reinforced-concrete arch bridge consisting of five spans of about 127 feet each, known as the Rye Outlet bridge.

Two sites for the Kensico dam were explored by borings and test-pits: One immediately below, and the selected site, about 400 feet above, the old dam. The old dam was a rolled-earth embankment with a masonry core-wall, only a portion of which was founded on the rock. The adoption of the upper location necessitated drawing the water out of the old reservoir. In order to maintain the supply which served a portion of The Bronx, two substitute reservoirs were built farther up the valley within the basin of the new reservoir. These substitute reservoirs

The construction of cut-and-cover aqueduct. In the foreground the concrete invert, or bottom, is being placed and immediately back of it are the steel inside forms, followed by a section where tbe steel outside forms also have been placed ready to receive the concrete, brought on the railroad and lifted into place by the locomotive crane. In the background is completed aqueduct ready to be covered with earth embankment.

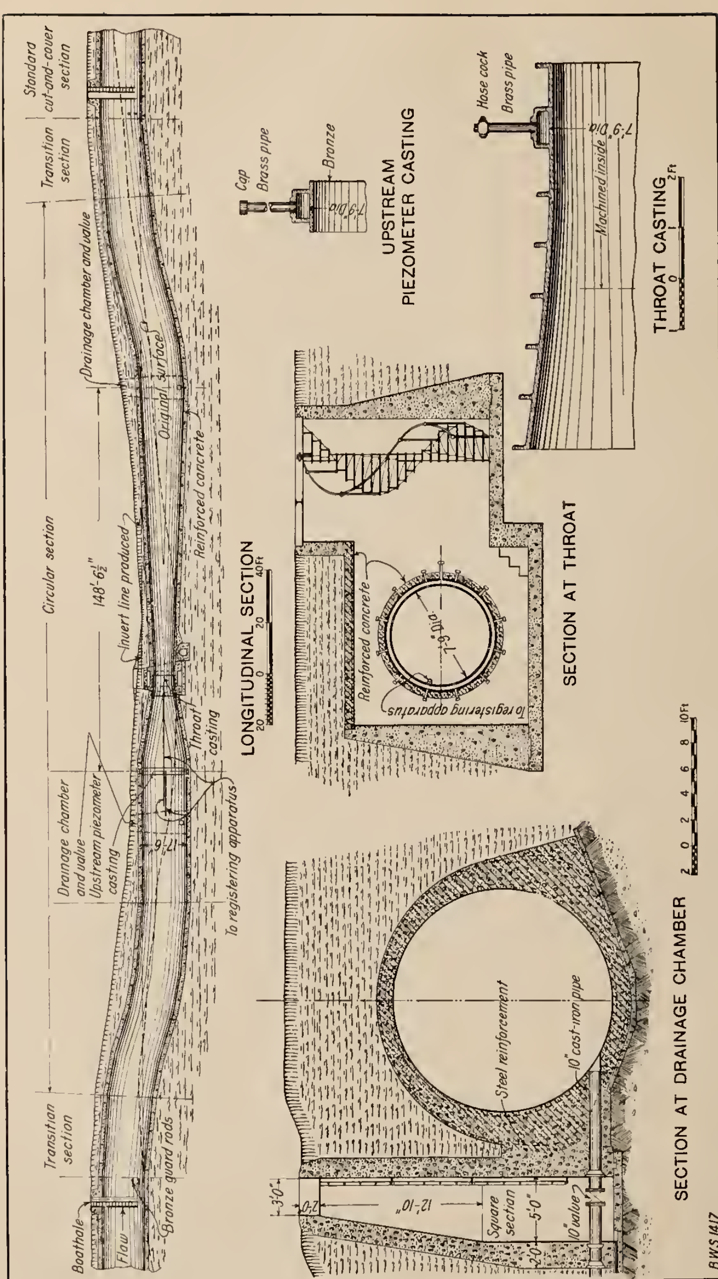
were formed by two rolled-earth dikes with timber core-walls, one across the Bronx valley, and the other across the valley of the Rye pond outlet. These two temporary reservoirs were inter-connected by a small tunnel and supplied the Bronx conduit through a 36-inch riveted steel pipe. In order to secure a good quality of water in the substitute reservoirs, about 186 acres of swamp were cleared and covered with a layer of earth averaging a foot in depth, and the water before being drawn into the pipe line was passed through a temporary aerator just below Rye dike. A conduit through the dam serves permanently to maintain this supply from Kensico reservoir. The steel pipe was removed and the temporary works are now deeply submerged.

Kensico dam is a gravity masonry structure of cyclopean concrete. The upstream face is of precast concrete blocks. The concealed portion of the downstream face below the final grading was molded against wooden forms, above which the remainder of this face is of cut-stone masonry. The entire dam is divided into sections by transverse expansion-joints about 79 feet apart longitudinally. These expansion-joints are faced on one side with concrete blocks forming a series of vertical tongues and grooves against which the masonry of the adjoining section was built. Near the upstream face a thin copper strip was placed across each expansion-joint, continuous from bottom to top, to act as a water-stop. The contraction and expansion are caused by changes of temperature and result in a slight opening and closing of the joints from season to season.

Drainage wells * 15 feet apart, longitudinally, formed of hollow blocks of porous concrete, extend from an inspection gallery below the top of the dam near the upstream face to an inspection gallery near the level of the reservoir bottom, which in turn connects with a transverse drainage gallery leading to a covered waste channel downstream from the dam, which discharges into the Bronx river.

The downstream face of the dam was given a dignified architectural treatment in harmony with the engineering fundamentals. For the profile of the downstream face a true hyperbola was adopted. Since the dam is divided for structural reasons by twenty-two expansion-joints, its downstream face has twenty-one panels and two terminal structures. At each expansion-joint there is a massive band of rusticated stone, 15 feet wide, projecting boldly from the general surface. These bands separate the panels, the fields of which are of roughly-squared stone masonry surrounded by borders 3 feet 6 inches in width of dimension stone cut to flat surfaces. To add interest to the panels, dimension-stone headers 1½ feet square are spaced throughout the fields to a diamond pattern and set to project slightly. A large proportion of the hight of the dam in the central part of the valley is below the level to which the earth has been graded against the dam. From this it results that thirteen of the panels are of uniform hight, while at each end four panels on the hill slope make a triangular wing. At the foot of each slope, where the inclined portion of the visible bottom of the dam joins the horizontal portion, the panel forming the end of the main part of the dam is advanced beyond the other panels to form a pylon. The whole length of the dam is crowned by a massive entablature, including a crudely-carved frieze and a very heavy torus surmounted by a simple parapet. All this stonework is of coarse texture and bold relief, in harmony with the massiveness and strength of the dam. All stone for the dam, including that used in the concrete, was obtained from a quarry, developed especially for the purpose, in a hill one mile east of the dam site and so situated that the scar in the landscape would not be visible from any highway.

* To intercept slight seepage into the masonry.



One of the Venturi meters in the Catskill aqueduct.

A public highway traverses the top of the dam, approaching from the east over a 3-arch masonry bridge across the nearby waste channel of the reservoir. Each terminal of the dam is surmounted by a circular pavilion of granite. Along the level portion of the visible base of the dam extends a masonry terrace 32 feet broad, 10 feet above the adjacent earth. Beneath the terrace are placed the Lower gate-chamber, controlling blow-off pipes and connections to Bronx conduit, and storage spaces for use of the maintenance force. At each end of the terrace is a pair of small square pavilions surmounting a flight of steps leading down from the terrace to the driveway level. The length of the level part of the visible base of the dam, and of the terrace, is 1,025 feet. The vertical hight of the exposed face, from the terrace to the top of the parapet, is 133 feet, but the maximum hight from lowest foundation to top of parapet is 310 feet. A shallow rectangular pool, with fountains, parallels the terrace and is separated from it by a strip of parking.

The area down-stream from the dam was utilized for the disposal of surplus materials from the excavations for the foundation, for the concrete block yard, the labor camp, for storage of cut granite, and for other construction purposes, and is being laid out as a park with which the northern end of the Bronx River parkway, extending from New York City, will connect. In this way the most monumental structure of the Catskill system will have a suitable approach and setting.

Surveys for this reservoir were begun in May, 1906, and the contract for the dam, reservoir and substitute supply works, was awarded in December, 1909. The amount of the contract, based on the bid prices and the approximate estimate of quantities, was $7,953,050. The amount of the bond required was $1,000,000 and the date set for the completion was February 14, 1920. The contract required that by November 14, 1917, the dam should be sufficiently completed to store water to Elevation 315; and that the dam be effectively completed to its full hight (Elevation 370) by April, 1919. Unprecedented progress in masonry laying developed through the methods employed brought the dam to its full hight in October, 1915, making possible the filling of the reservoir the following winter. During August, 1914, the record amount of 84,450 cubic yards of masonry was laid. Some of the quantities of materials required for the construction of the Kensico dam and its appurtenances are given in the table on page 65. *This reservoir was filled with Catskill water nearly four years earlier than was expected when the contract was prepared.*

This work, like all other construction except highway work, which is specifically exempted by law, was carried on in the legal working day of eight hours. For the most part, forces were employed but one shift each 24 hours.

Construction Camps and Equipment.—When at its hight, the work on the Kensico reservoir gave employment to about 1,500 men, who lived, many of them with their families, in a camp built by the contractor a few hundred feet downstream from the dam site. The camp was divided into Italian and American sections. There were provided sewerage and water-supply systems and dwellings which were generally one-story wooden structures, those occupied by families being two stories in hight. All doors and windows of the camp buildings were screened. Electric lights were provided. There were also a hospital, police regulations, fire protection, and kindergarten and schools for the children.

An evening school for men was one of the features of the camp. This school was originally operated by the Civic League of North America, but later was in a special public school district supported by The City. The 8-hour day gave plenty

With nearly 25,000 laborers in camps during construction, the Aqueduct Police protected communities near the waterworks. Their presence alone was a deterrent to those criminally inclined. They maintained order, protected person and property and enforced sanitary and other rules, as well as local ordinances and laws governing intoxicants, concealed weapons, speeding, etc.

of spare time to attend the school, where the elements of the English language and of national, state and city governments were taught; all in an effort toward good citizenship and promoting efficiency in the workmen. Camp schools were encouraged and assisted by the Commissioners personally. They were supported by private subscription together with the help of the Contractor.

Besides the large camp, which had accommodations for 1,200 persons, there were several small camps on outlying parts of the work. Of the men employed quite a number lived in the surrounding villages, but practically all outside of the limits of the drainage area of the Kensico supply, and in the larger communities not far away.

For carrying on the work on this reservoir, the machinery, railroads, derricks, and similar equipment cost over one and a quarter million dollars. This plant was operated largely by electricity obtained from the power-houses of the Edison Company in New York City. The current was transmitted in underground ducts at a potential of 13,000 volts to the Dunwoodie transformer station, where it was stepped up to 44,000 volts for transmission over a steel tower line on the aqueduct right-of-way from Dunwoodie to the site of the work. In the power-house at the easterly end of the dam site the current was stepped down to 2,200 volts for distribution. Field transformers further reduced the voltage to 440, 220 and 110 for the operation of rock drills, hoists, cableways, the rock-crushing plant and the lighting system. In the power-house were also two air-compressors of a capacity of 1,500 cubic feet of free air per minute. The 40 electric hoists on the work were all of 75 horse-power. At the excavations for the dam and at the quarry, besides many rock drills of the usual type, a large number of electric pneumatic drills were employed.

For constructing the main portion of the dam, stiff-leg derricks mounted in pairs on travelers were used. These travelers, as well as the cars bringing materials to them, operated on a system of elevated tracks supported on concrete piers about 20 feet high, which were left embedded in the dam. Two lines of traveler tracks running longitudinally with the dam permitted four travelers to be placed in pairs facing each other over a section of the dam between expansion-joints, thus making eight derricks available for each section of the dam. This whole system of tracks and travelers was elevated from time to time as the masonry progressed by means of two movable cableways of 1,860-foot span stretching across the dam site between timber towers 125 feet high. The cables were of lock-bar type, 2½ inches in diameter. For the upper 130 feet the reduced width of the dam permitted the use of only one traveler track.

Concrete blocks for facing the dam were cast in a yard 1,100 feet long below the dam. A traveling platform carrying three concrete mixers, each of one cubic yard capacity, spanned the form bed and moved on rails extending longitudinally through the yard. The forms for the blocks were of steel and were set in rows along the tracks, so that as the traveler advanced each mixer discharged concrete into a separate form. The blocks when sufficiently hardened were stacked by locomotive cranes and stored at least three months before being built into the dam.

Taking advantage of favorable outcrops of rock about one mile east of the dam site, quarries were developed for supplying the stone needed for the various kinds of masonry. Here a rock-crushing plant having an output of 150 tons an hour and a cutting shed for dimension-stone masonry with a daily output of 50 cubic yards of dressed stones were established. The crushing plant contained a 60-inch by 84-inch jaw crusher, one of the largest ever built, a 36-inch by 72-inch intermediate jaw crusher, a No. 8 McCully gyratory crusher and a pair of 60-inch rolls for further reducing the size of the crushed product. The product of the crushers was lifted by rubber belt conveyors 36 inches wide carrying steel buckets.

The southerly portal of Bonticou tunnel and the beginning of the adjoining section of cut-and-cover aqueduct. In the background are the Contractor's stone-crushing and screening equipment and storage piles of broken stone for concrete. Observe the stone boundary wall marking the limits of the City's property.

The main rotary screen was 8 feet in diameter and 30 feet long, equipped with cast manganese steel plates. The crushed stone and dust were carried from the main screen by belt conveyors to the storage bins with hopper bottoms which discharged into cars running on tracks under the bins. The bins had a capacity of 7,280 cubic yards of crushed stone and 740 cubic yards of screenings. The whole was electrically operated by 8 motors aggregating 1,120 horse-power.

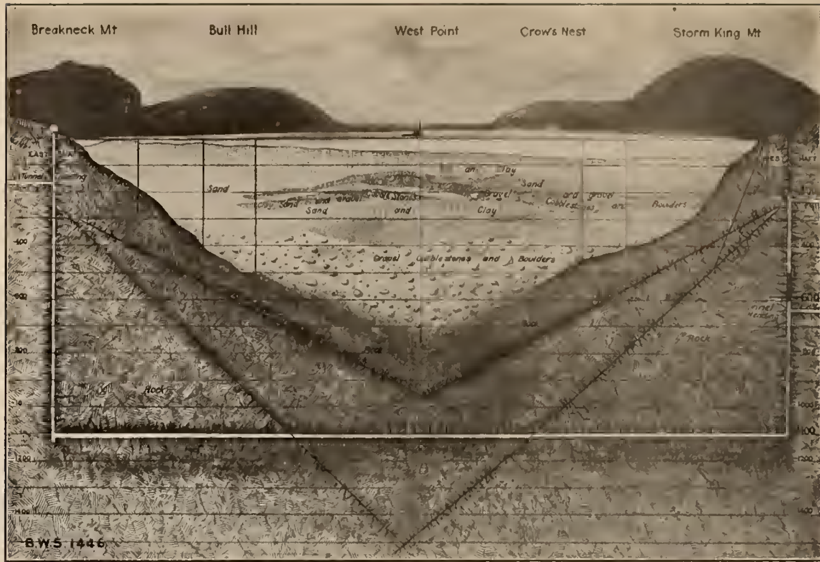
The stone cutting yard was 225 feet long and 60 feet wide, equipped with a 25-ton Shaw electric crane, 9 Oldham surfacing machines, each of which did the

Peak gaging chamber in Catskill aqueduct south of Peak tunnel.

work of about 10 hand cutters, and 50 plug drilling machines. Altogether about 80 stone cutters were employed at this yard.

Hill View Reservoir

Hill View reservoir is located in the City of Yonkers, just north of the New York City line, and 15 miles south of Kensico reservoir. Its function is to equalize the difference between the use of water in The City as it varies from hour to hour and the steady flow in the aqueduct. It is an uncovered, artificial reservoir of the earth embankment type. It holds 900,000,000 gallons of water with a depth of 36½ feet, and has a water surface of 90 acres. The contract for its construction was let for $3,270,000, in December, 1909. It was first filled December 29, 1915.



The Hudson River crossing of the Catskill aqueduct looking downstream toward West Point, 3½ miles distant. Beneath the view is a cross-section of the river showing the old rock gorge of pre-glacial times and the location of the tunnel in the granite beneath the gorge. There are also shown diamond drill holes made to explore the rock to determine the location of the tunnel.

The drill chamber excavated in the rock 250 feet below the top of the shaft on the west side of the Hudson river, from which two of the long inclined holes under the river were driven. The drilling machine is shown, also the pump for forcing water through the hollow drill rods to keep the drilling bit cool and free from chips of rock, which are washed up into the chamber through the space between the drill rod and the side of the drill hole.

On the inside of the reservoir, the embankment is protected by six inches of concrete on the bottom and eight inches of concrete on the lower portion of the slope; the upper portion of the slope, above the berm which is 22 feet above the bottom, is protected by rubble stone paving and riprap. The concrete lining is not intended or constructed for water-tightness, but to protect the earth slopes and bottom from erosion. The earth banks are water-tight. The top and outside slopes of the embankment are covered with top-soil and grassed. Much effort has been made to produce the effect of natural hill slopes in the grading, and with success. The path around the top of the reservoir is 8,600 feet long.

The two chambers of Indian Brook steel-pipe siphon and adjoining cut-and-cover aqueduct in the Highlands of the Hudson river north of Garrison.

The reservoir is divided into two basins by a wall 2,740 feet long that contains the by-pass aqueduct so that either one or both basins may be used or be by-passed whenever required, or water delivered directly into the City tunnel. The water is controlled by sixteen 5-foot by 15-foot sluice-gates, five in the Uptake gate-chamber and eleven in the Downtake chamber.

The principal items of work on Hill View reservoir included the following:

Excavation	2,900,000 cubic yards
Embankment	2,900,000 cubic yards
Soil	100,000 cubic yards
Concrete in chambers, dividing wall and lining	149,000 cubic yards
Concrete in shafts and tunnels	13,000 cubic yards
Portland cement	218,000 barrels

Kensico Influent weir and chamber where the Catskill water enters Kensico reservoir. The Kensico by-pass aqueduct begins at the left side of the chamber.

The tunnels mentioned in the table are of the pressure type and form the connections between the reservoir and the Yonkers pressure tunnel of the Catskill aqueduct on the northerly end, and the City tunnel at the south.

Catskill Aqueduct North of the City

There are four distinct types of aqueduct, cut-and-cover, grade tunnel, pressure tunnel and steel-pipe siphon, north of the City line. These are shown on page 20. The cut-and-cover type forms 55 miles of the aqueduct, is of horseshoe shape in

Harlem Railroad steel-pipe siphon, looking northward toward Sarles tunnel. The siphon chamber superstructures are of vitrified paving brick culls with cast concrete-stone trimmings and reinforced-concrete tile roofs. Note the steel towers of the aqueduct electric power transmission line.

cross-section, constructed of concrete without steel reinforcement, and covered with an earth embankment. It is 17 feet high by 17 feet 6 inches wide inside north of Kensico reservoir and 17 feet 6 inches by 18 feet between Kensico and Hill View reservoir. This is the least expensive type and so was used wherever the elevation and nature of the land permitted.

Where hills or mountains cross the line and it would have been impracticable or uneconomical to circumvent them, tunnels at the natural elevation of the aqueduct (hydraulic gradient) were driven through them. There are 24 of these grade tunnels, aggregating 14 miles. They, also, are horseshoe shape, 17 feet

Contractor's plant at the top of a City Tunnel shaft (1); (2) a reinforced concrete caisson being sunk through sand to rock for a shaft in Brooklyn; (3) interior of a valve chamber on top of a finished shaft; (4) a shaft top nearing completion showing a riser pipe and shaft cap; (5) looking down into a shaft during the process of sinking; and (6) steel riser pipes in a shaft ready to be imbedded in concrete.

high by 13 feet 4 inches wide, and lined throughout with concrete. They are on a steeper gradient than the cut-and-cover portions, to compensate for their smaller waterway, chosen for economy of construction.

Where deep and broad valleys were crossed and there was suitable rock beneath them, circular tunnels were driven deep in the rock and lined with concrete. There are 7 pressure tunnels, totaling 17 miles, with a diameter of about 14 feet. A shaft at each extremity connects each pressure tunnel with the adjacent portions of the aqueduct, with one exception. This exception is the junction between Bryn Mawr steel-pipe siphon and Yonkers pressure tunnel; the three pipes, each 11 feet in diameter, enter the hill at an elevation 167 feet below hydraulic gradient of the aqueduct and are sealed into the rock in three branch tunnels, which converge into the main tunnel 16 feet 7 inches in diameter. The City tunnel, described later, is also a pressure tunnel 18 miles long.

Drainage shafts were constructed so that each pressure tunnel can be unwatered for inspection, cleaning or repair. For the Rondout and Wallkill pressure tunnels the drainage shafts are near the large streams and intermediate between the end shafts. For the pressure tunnel under Croton lake, the Downtake shaft is also the Drainage shaft and contains a connection to the lake. Yonkers pressure tunnel can be drained by gravity through the Bryn Mawr steel-pipe siphon, with which it is connected. Besides the end and drainage shafts other shafts were sunk to aid in excavating and lining the tunnels. These construction shafts were afterwards sealed with deep concrete plugs just above the tunnel and partially refilled, near the top, with rock debris and earth supported on concrete arches across the shaft.

The Hudson river is crossed by means of a tunnel wholly in granitic rock, at a depth of 1,114 feet below sea-level, between a shaft at Storm King mountain on the west bank and another shaft on the east side of the river at Breakneck mountain. The top of the West shaft is closed by a deep concrete plug, but the East shaft, which is the drainage and access shaft for the Moodna-Hudson-Breakneck pressure tunnel, as well as a waterway, required a removable cover, and for it steel castings and forgings of unusual size and shape had to be manufactured. The Drainage shaft is 14 feet in diameter inside the concrete inner lining, which protects the 15-foot-diameter steel interlining, outside of which concrete is solidly packed against the rock. About 10 feet above sea-level, this shaft is covered by a steel casting nearly hemispherical in shape. This dome rests on a cast-steel ring called the curb. To hold the dome in place against the pressure of the water when the aqueduct is in service, which at this point is 180 pounds per square inch, equivalent to a head of 410 feet, there are 36 anchor-bolts, each 4½ inches in diameter and 50 feet long, made of nickel-chrome steel. These bolts go through bored holes in the flange of the dome and the curb, and through steel sleeves to a cast-steel anchor-ring 46 feet farther down. The object of these sectional steel sleeves is primarily to insure the application of the anchorage stresses at a suitable depth in the rock, secondarily to permit the removal of the bolts if desired in connection with the removal of the cover or for inspection and also for convenience and necessary adjustments during construction operations. The top and bottom sections of these sleeves are of cast steel, each with 47 collars on the outside to afford a good grip on the concrete; the middle sections are commercial pipe.

Steel-pipe siphons were used in valleys where the rock was not sound or where for other reasons pressure tunnels would be impracticable. These steel pipes are made of plates from 7/16 inch to ¾ inch in thickness riveted together, and are 9 feet and 11 feet in diameter. They are lined with two inches of cement mortar, enveloped with concrete and covered with an earth embankment. There

Pressure tunnel: (1) drilling tunnel "heading" and "bench"; (2) loading dynamite into the holes; (3) removing the "muck"; (4) hauling "muck" out and concrete in; (5) placing concrete lining around steel forms; and (6) grouting crevices in the rock back of the lining.

are 14 of these siphons, aggregating 6 miles. Three pipes are required in each siphon for the full capacity of the aqueduct, but only one pipe has been completed in all the siphons. The remaining pipes are now needed and must be constructed as soon as market conditions will permit. These pipes are not true siphons but are given this name because of their approximate resemblance to an inverted siphon.

Protecting the Quality of the Water

Aeration.—In connection with the Headworks of the Catskill aqueduct, at the Ashokan reservoir, and also at Kensico reservoir, an aerator capable of treating all the water which will flow in the aqueduct has been built. These two aerators are substantially alike and are great fountain basins, approximately 500 feet long by 250 feet wide, each containing about 1,600 nozzles, through which jets of water are thrown vertically into the air. The nozzles are so designed that the water is divided into fine spray, thus permitting thorough admixture of oxygen from the atmosphere and removal of undesirable gases and other matters causing tastes and odors. These are the products of growths of microscopical and other very small vegetable and animal organisms which cannot wholly be prevented from occurring at times in reservoirs and lakes. The jets have been so arranged as to be pleasing in appearance, and the fountains are well worth visiting when in operation.

Coagulation.—At a number of places in the Catskill watersheds there are banks of very fine clay-like earth on the hill slopes or along the streams and margins of the reservoirs. Under certain conditions of storm or very rapid run-off of water from the steep surfaces of the hills and mountains, some of this fine earth is carried into the streams and by them into the reservoirs, making the water turbid. Most of this turbidity settles in the reservoirs during the period of storage of the water. At times, however, some of the finest turbidity may be carried into the aqueduct rendering the water unattractive in appearance. To correct this fault whenever it may occur (which will probably be only at long intervals) a coagulating plant has been installed on the aqueduct about two miles north of Kensico reservoir. This plant is so arranged that it can mix into the water flowing in the aqueduct small quantities of a harmless coagulant which will cause the very fine clay particles to settle out of the water while passing through Kensico reservoir.

Chlorination.—Within the screen chamber downstream from Kensico reservoir chlorine is introduced into the water flowing in the aqueduct for the destruction of germ life. The gas is delivered at the chamber compressed to a liquid state in steel containers holding 100 pounds each. The chlorine is introduced into the water through a manually controlled system of piping, meters and valves, by which the gas, transformed from its liquid state when released from the cylinders, is measured and delivered to specially designed injectors. The resulting mechanically mixed solution is carried by rubber hose confined within a slotted pipe to any desired depth below the surface of the water in the aqueduct, where the gas is instantly disseminated. For the present four control units have been installed, so arranged that they may be operated singly or in combination, together capable of supplying gas in any quantity up to 1,200 pounds per day and sufficient to effect a maximum sterilization of all flows up to 350 million gallons per day. Chlorine is thus used to insure the practical sterilization of the water before it

Kensico dam and reservoir and Kensico bridge near completion, viewed from the State highway which passes along the easterly side of the reservoir.

goes to the City and is wholly neutralized or dissipated before the water reaches the distribution pipes.

Filtration.—Provision for a filtration plant was made by the acquisition of 315 acres of land at Eastview, near Tarrytown, close to the line of the aqueduct, and about two miles below Kensico reservoir. Here a connection chamber was built in the aqueduct, so that water can be diverted to, and received back from, the filter plant. Designs for the filters are in progress. They are to be rapid sand filters of the so-called mechanical type. The plant will necessarily be very much larger than any which has yet been built.

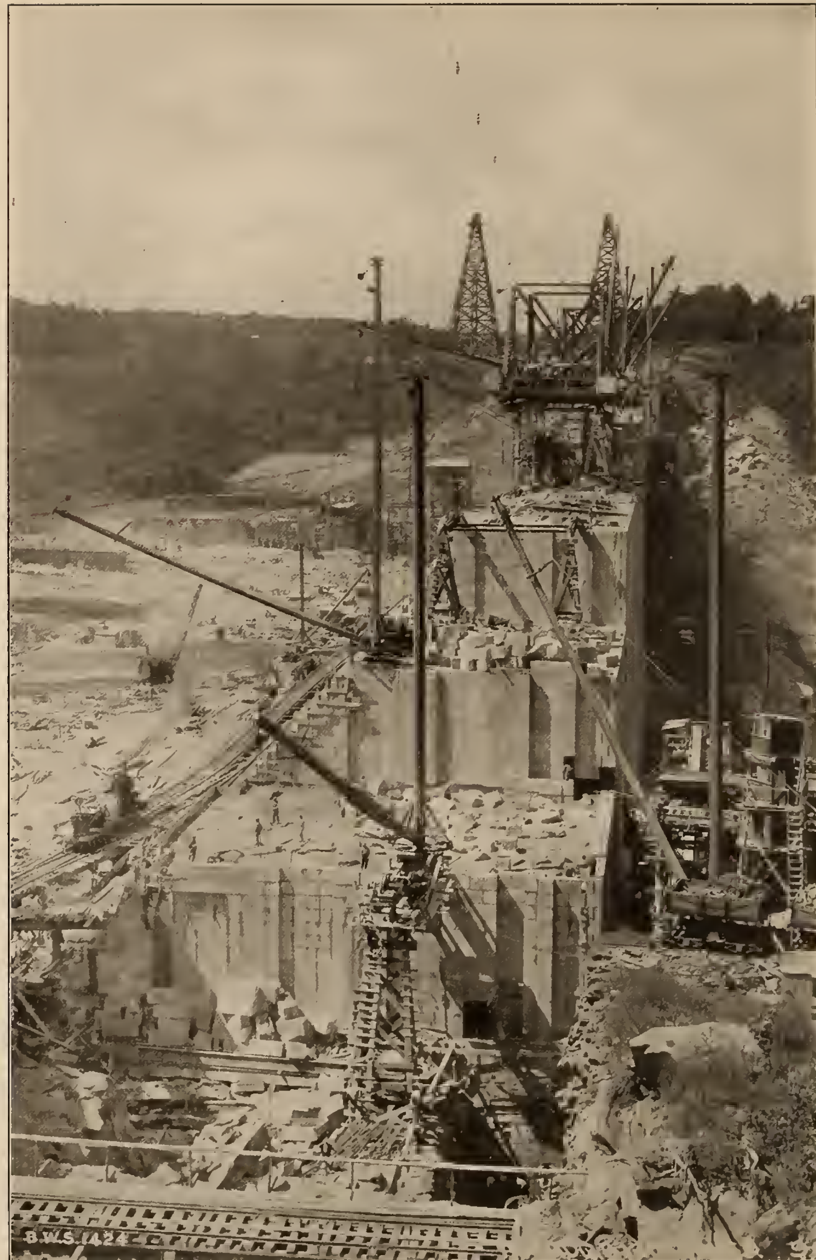
Storage.—In addition to the treatment whenever required by the methods outlined above, Catskill water constantly receives benefit from its long storage in the great reservoirs of the system. In them sedimentation, bleaching by the sun, oxygenation by the winds and sterilization by natural processes, all go on more or less continually. From each reservoir the water can be drawn at the depth at which the water is in the best condition at any time.

Sanitary Improvement of the Watershed.—The Esopus watershed is sparsely settled, but the few villages and hamlets there are, as well as many of the scattered houses, are situated close to the creek and its tributaries, because of the conformation of the country, the steep mountainous slopes forcing the settlements to the bottoms of the narrow valleys, close to the streams. The all-the-year-around population of the whole watershed is small, being only about 5,300. The summer population is increased to about 11,000 by the great influx of visitors between the middle of June and the middle of September. In order to prevent the pollution of the streams, the sanitary facilities on hundreds of premises have been improved so as to keep the sewage from getting into the water. Efforts have been made to raise the sanitary standards of the communities and secure their co-operation along these lines for local benefit as well as for the improvement of New York City's water supply.

The City Tunnel

From Hill View reservoir, Catskill water is delivered into the five boroughs by a circular tunnel in solid rock reducing in diameter from 15 feet to 14, 13, 12 and 11 feet. The total length of the tunnel is 18 miles. From two terminal shafts in Brooklyn, steel and cast-iron pipe-lines extend into Queens and Richmond. A 36-inch flexible-jointed, cast-iron pipe, buried in a trench in the harbor bottom, has been laid across the Narrows to the Staten Island shore, whence a 48-inch cast-iron pipe extends to the Silver Lake reservoir, holding 435,000,000 gallons. The total length of this delivery system is over 34 miles. The tunnel is at depths of 200 to 750 feet below the street surface, thus avoiding interference with streets, buildings, subways, sewers and pipes. These depths are necessary, also, to secure a substantial rock covering to withstand the bursting pressure of the water inside and afford the requisite watertightness. The waterway of the tunnel is lined throughout with Portland cement concrete.

The City tunnel, which is the longest tunnel in the world for carrying water under pressure, or for any other purpose, was constructed from 25 shafts, including the Downtake shaft at Hill View reservoir, about 4,000 feet apart, located in parks and other places where they interfered very little with traffic. Through 22 of these shafts the water is delivered into the street mains. These connections from the tunnel to the mains are made by means of vertical riveted steel pipes



Kensico dam during construction, showing the division of the dam by the expansion-joints. The two cableways spanning the valley aided in handling materials and equipment. The system of derricks on travelers and the single derricks, for placing stones and concrete, are also shown, as well as the railroad tracks for delivering materials to the derricks.

(called risers) embedded in concrete in the upper part of each shaft and lined with concrete to prevent corrosion inside. Concrete fills all spaces outside the risers, sealing the shafts against the escape of water excepting through the pipes. Provision is made at Shaft 11 in Morningside park and at Shaft 21 on the shore of the East river, at Clinton and South streets, Manhattan, for unwatering the tunnel, whenever necessary, for inspection, cleaning or repairs.

Shaft 1 was sunk for construction purposes only and was sealed and refilled. At the top of each of the twenty-four other shafts a chamber has been constructed to contain the valves and other appliances for controlling the admission of water from Hill View reservoir, the flow and pressure of the water from the tunnel into the street mains and for the unwatering apparatus. Unusual features in connection with the operation of the tunnel are the bronze riser valves in the shafts, 48 inches and 72 inches in diameter, and the section valves, 66 inches in diameter, also of bronze. The former are located about 100 feet below the top of sound rock and are designed to close automatically in case of an important break in the valve-chamber or in the street mains, causing an abnormally large flow of water. They can also be closed by hand from within the chambers at the shaft tops. The section valves, two in number, are located across the main tunnel, at the feet of Shafts 13 and 18, and will permit the tunnel to be divided into parts and drained in sections without putting it entirely out of commission. Next to each section valve on either side are bronze reducing pipes which are connected to steel castings embedded in the concrete tunnel lining. Approaching the valve on either side, the tunnel is of conical shape, reducing gradually from the standard tunnel diameter, which is 14 feet at Shaft 13, and 13 and 12 feet adjacent to Shaft 18. Each section valve is operated by a hydraulic cylinder in the shaft-head chamber.

At Shaft 3, at the northerly end of Jerome Park reservoir, and at Shaft 10, in St. Nicholas park, connections were made to the Jerome Park reservoir and the Croton aqueducts respectively. Below 24th street, there are connections at each of the shafts, except Shaft 24, to the high-pressure fire service, with electrically-operated valves at the shafts controlled from the fire pumping-stations.

The cost of the portions of the Catskill aqueduct within the City limits, including the tunnel, pipe-lines, appurtenances and Silver Lake reservoir, is $23,000,000.

Shafts of the City Tunnel

Shaft	Location	Depth (Feet)
Downtake,	Hill View reservoir	308
1	241st street and Jerome avenue, Van Cortlandt park	243
2	Mosholu and Jerome avenues, Van Cortlandt park	226
3	Sedgwick avenue and Mosholu parkway, Jerome Park reservoir	216
4	196th street and Jerome avenue, Jerome Park reservoir	240
5	183rd street and Aqueduct avenue	224
6	176th street and Aqueduct avenue	277
7	167th street and Sedgwick avenue	350
8	165th street and High Bridge park	475
9	150th street and St. Nicholas avenue	439
10	135th street and St. Nicholas park	403
11	121st street and Morningside park	413
12	106th street and Central park	260
13	93rd street and Central park	250
14	79th street in Central park	237
15	65th street in Central park	218
16	50th street and Sixth avenue	216
17	Sixth avenue in Bryant park	222
18	24th street and Broadway, Madison square	203
19	6th street and Fourth avenue, Cooper square	708
20	Delancey and Eldridge streets	740
21	Clinton and South streets	714
22	Sands and Bridge streets, Brooklyn	715
23	Flatbush avenue and Schermerhorn street, Brooklyn	310
24	Ft. Greene park at Myrtle avenue, Brooklyn	321

Downstream face of Kensico dam and the unfinished park below, looking from the pavilion at the west end of the dam across the terrace at the base of the dam, the pool, with three kinds of jets being tried, and the cascade basins.

Silver Lake Reservoir

The terminal reservoir for the Catskill water system, located on Staten Island, is about 2,400 feet long and 1,500 feet wide. It holds 435,000,000 gallons. Earth embankments close natural depressions in the ground and a dividing dike paved with concrete forms two basins. From a gate-chamber built in this dike, reinforced concrete conduits extend to the boundary of the reservoir, and cast-iron pipes prolonged from them connect with the Narrows siphon and with the Staten Island service mains.

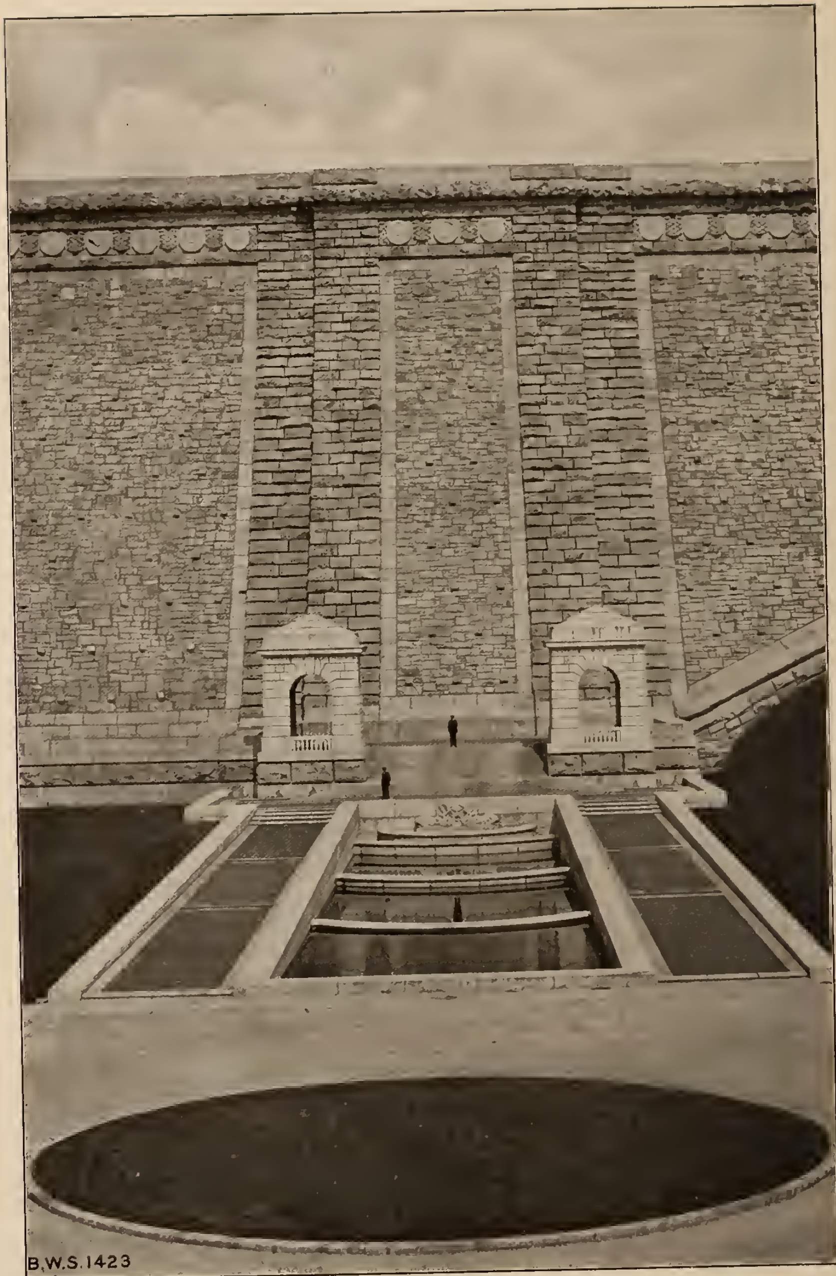
Area of water surface	54 acres
Area of land	111 acres
Length of shore line	1.6 miles
Available depth	35 feet
Length of North basin	1,100 feet
Width of North basin	1,200 feet
Length of South basin	1,200 feet
Width of South basin	1,700 feet
Elevation above tide	228 feet

Contractors' Forces

During the years of active construction the contractors' forces ranged from a minimum of 500 to a maximum of 17,243, counting only the men actually and directly at work on the City's structures. To these must be added men engaged upon incidental work for the contractors, the men in camp but for one reason or another idle on any given day, and the large number of men in cement, metal and other manufacturing establishments, widely scattered over the country, engaged on the production of materials, equipment and supplies for the work. Hence, it is no exaggeration to say that in addition to the numbers given above, thousands of persons have been directly and indirectly employed upon this great undertaking of the City of New York, bringing the maximum total to approximately 25,000.

Explorations and Surveys

In order that the Catskill aqueduct might be most safely and economically located, extensive surveys and sub-surface explorations were made of both topographical and geological character. Of the greatest assistance in the initiation of this work were the topographical sheets of the U. S. Geological Survey and the maps which had been made by the Commission on Additional Water Supply and others who had reported upon the project before the creation of the Board of Water Supply. Nevertheless, it was necessary for the Board's engineers to make about 3,000 miles of line surveys, besides the very extensive topographical surveys of the reservoir sites and the final location of the aqueduct. The key points to the aqueduct location were the point of departure from the Ashokan reservoir and the crossing of the Hudson river, although the crossings of the Rondout and other valleys were also important. It had been suggested early that the aqueduct should start from the easterly end of the Ashokan reservoir, but surveys and investigations showed that a large saving could be effected and several advantages secured by the adoption of the present location for the headworks of the aqueduct and the division of the reservoir into two basins.



The East Pylon and Cascade basin of Kensico dam showing details of the architectural design and the rugged character of the stone-work in keeping with the massiveness of the structure.

For determining the exact location of the deep valley crossings, geological explorations by means of borings into the rock, with diamond and shot drills, were necessary, and were carried on under the immediate supervision of skilled, practical geologists. Such explorations were also made for the locations of the dams and for other features of the work. In the aggregate, these borings amounted to 240,000 feet, or 45 miles.

Before the Board began its work the nature of the Hudson river bed from Albany to the sea, and the depth of the bed-rock beneath it were matters of conjecture. Definite, dependable information must be had; therefore, the Board began almost immediately after preliminary organization of its engineering bureau, investigations to determine where the river could be crossed safely and economically. A number of possible crossings were explored, but all of them developed great difficulties, excepting the one at the northerly end of the highlands, where a band of granite crosses the valley, outcropping in Storm King mountain on the west side and Breakneck mountain on the east side. Endeavors were made by boring from scows on the surface of the river to determine the depth to the bed-rock, but this work proved tedious and expensive, and at best could give information at only a few points. Winds, tides and traffic and the severe winter weather all militated against this method of exploration. It was therefore determined to start a test shaft on each bank as close to the edge of the river as was practicable, and when a suitable depth had been attained, to drill from a chamber in the side of the shaft inclined bore holes out under the river. From each shaft two holes were drilled. In each case the first hole was inclined rather steeply downward so as to reach the center of the valley at a depth about 1,500 feet below the surface of the river. The holes were each about 2,000 feet long. Many interesting difficulties were overcome and samples of the rock obtained for the whole distance. The second holes were then driven at a much flatter slope, taking the chance that they might possibly run out of the rock before reaching the center of the valley. These two holes, however, were wholly in rock and intersected at a depth of about 950 feet. Meanwhile a drilling from a scow near the center of the river had reached a depth of 768 feet without entering the bed-rock, although having developed evidences of being near the rock, when the hole was lost through accident. With this information in hand it was determined to locate the tunnel across the river at a depth of 1,100 feet below the river surface, being assured that at the shallowest place it would have somewhat more than the necessary minimum of 150 feet of sound rock above its roof.

Some deep and difficult drilling was required also in connection with the location of the City tunnel and its shafts, particularly in the lower east side of Manhattan Island, where the old bed of the East River was crossed, which lies west of the present location of that river. Hundreds of test pits, auger borings, wash-drill borings and other forms of sub-surface explorations were used in various parts of the aqueduct. The extensive and useful information gained in this way was of great aid to the engineers designing the works and to the contractors in bidding on their construction. It is a safe statement that the cost of such explorations was saved many times over in the economies resulting therefrom.

Measurement of Water

Measurement of the Catskill water begins with the determination of the rainfall on the watersheds by means of so-called rain gages placed at a number of carefully selected points of observation. The water flowing in the streams is also

Hill View reservoir, looking north, showing the Downtake chamber at the beginning of the City tunnel in the foreground and the Uptake chamber in the background where the Catskill aqueduct discharges into the reservoir. The buildings are of cast concrete-stone and like all other buildings along the aqueduct, roofed with reinforced-concrete tiles

measured periodically at selected gaging stations. By means of the data thus obtained the productiveness of the watersheds can be estimated from time to time.

The proper interpretation of data upon rainfall and its yield in the form of run-off is a complex and very important science in connection with waterworks construction and operation. Records of this nature have been kept for half a century on the Croton watershed and disclose astounding variations in seasonal, yearly and periodic yields. Some years the rainfall has been two-thirds greater than in other years; again, for instance, the average flow from 1887 to 1904 was 30 per cent greater than for the preceding 18 years. It is one of the duties of the responsible officials and the function of the large reservoirs in the watersheds to impound the supply when it is ample in order to conserve it for use during years of drought.

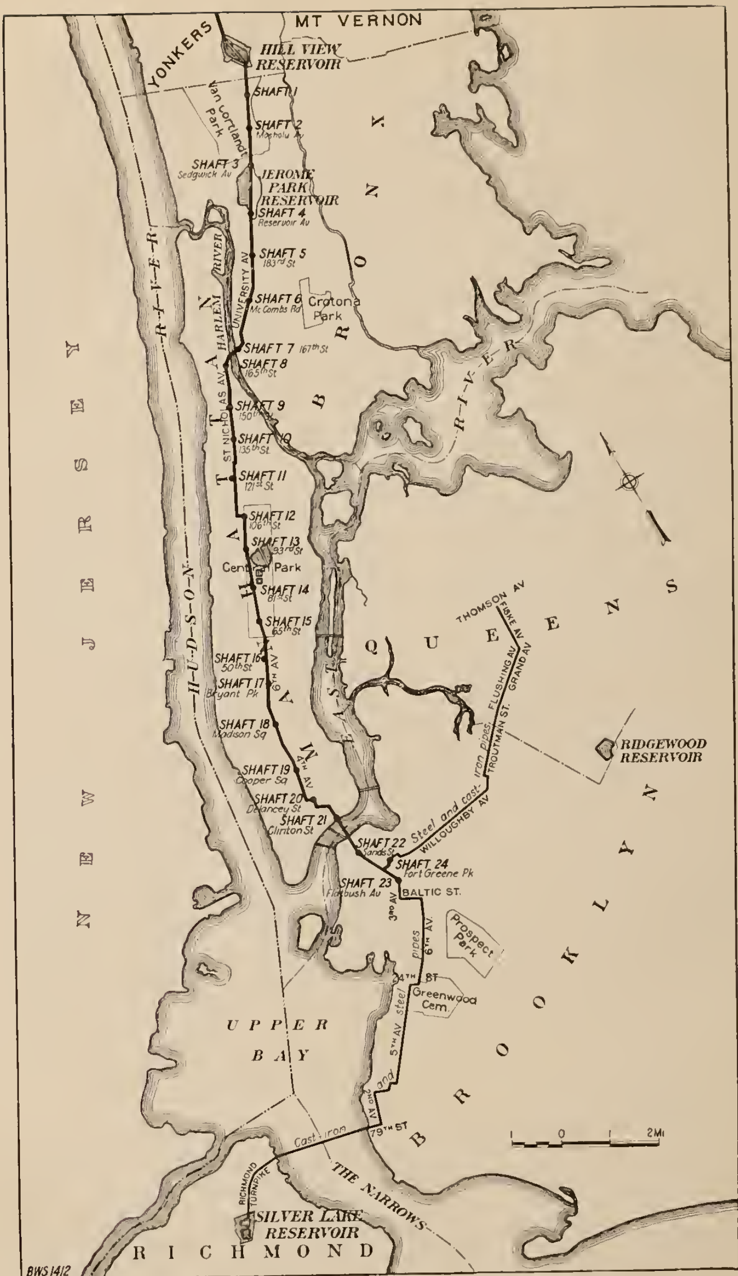
To measure the water drawn from the big reservoirs very large Venturi meters have been built in the aqueduct. These are the largest water meters ever constructed. There is one just below the Ashokan reservoir, a second just above the Kensico reservoir, a third where the water is drawn from the Kensico reservoir, and a fourth just north of Shaft 2 in the City tunnel. Each of the first three meters is 410 feet long, of reinforced concrete excepting for the bronze throat castings and the piezometer ring, which is also of cast bronze. In addition to these large meters, five gaging chambers have been built at various points along the aqueduct where the flow of water can be measured by means of current meters. The meter at Shaft 2 measures all the Catskill water supplied to The City. In the connection to Jerome Park reservoir a Venturi meter will measure the flow in either direction. In the City tunnel chambers a Venturi meter upon each connection between the tunnel and the distribution pipes in the streets measures the water delivered locally.

Landscape Engineering

In connection with the tunnels and other large excavations made for the Catskill aqueduct, huge piles of "spoil," that is, excavated stone and earth, had to be disposed of. Rather than leave these as bare, ugly blotches upon the landscape, the Board has endeavored to grade them to pleasing forms and to cover them with vegetation. In some places unsightly spoil banks or excavations have been concealed by skillful planting of trees and bushes. In designing the earth dams or dikes, also, attention has been paid to their contours so that they fit into the surrounding topography. Such work has been done under the guidance of landscape engineers who have advised also in the limited ornamental planting and parking of the surroundings of the structures along the aqueduct, particularly at the important reservoirs. Expenditures for these purposes have been very small, but the results during the years to come will be pleasing, out of proportion to the cost.

Forestation of Reservoir Lands

The large areas of land around the Ashokan and Kensico reservoirs were partly wooded. These woods have been improved by removing dead trees and undesirable undergrowth, and under-planting in places where the forest stand was thin. Besides this, large open areas have been planted with young evergreen trees, of which about three million have been set out around the two reservoirs. A good evergreen forest cover protects the shores of the reservoirs from erosion,



Map of City tunnel and conduits of the Catskill aqueduct.

from undesirable growths of weeds or from the pollution resulting from the cultivation of the lands, as well as improving the general appearance of the reservoir surroundings. This work has been done at small cost.

Changes in Construction

In the total 50 miles of tunnels, in the whole Catskill aqueduct, some geological uncertainties were, naturally, encountered. To have developed them fully in advance would have been impossible, and an attempt to do so would have been extravagant in time and in money expended upon borings and other subsurface explorations. Likewise, to have constructed all those parts of the tunnels in which some slight doubt as to the strength or character of the rock arose during the progress of excavation, so strongly as to have been beyond question in case an unsuspected weakness should develop at any of the doubtful places, would have been extremely costly. Instead, the common-sense, businesslike policy was adopted of making the structure at the few such places of abundant strength for the apparent condition of the rock and developing the weakness, if any existed, by subsequent thorough tests of the structure.

At four places such weaknesses were developed. In the Rondout pressure tunnel a short stretch of the lining was subsequently reinforced by an interlining made up of steel channel rings, welded and riveted together, and lined with concrete. At the easterly end of the Moodna tunnel, where it joins the Hudson siphon, a short supplementary tunnel was driven at a depth 400 feet below the original tunnel approaching the shaft on the west side of the river. Here a seemingly very slight chance had been taken, in rock of unusual apparent soundness, in order to utilize in the permanent structure the test shaft, 1,200 feet deep, sunk in order to determine the level at which the tunnel could safely be driven beneath the river. In this one case alone a few hundred thousand dollars were saved. In a portion of Eastview grade tunnel the rock penetrated was found, after construction, to contain an acid-forming mineral. The acidulous water percolating through this rock attacked the concrete tunnel lining. To overcome this trouble an inner lining of vitrified brick was built inside this portion of the tunnel. In the City tunnel, near Madison square, small cracks caused by compression of the rock under the water pressure in the tunnel were made tight by sheet copper lining, at a relatively small expense. Here the yielding of the rock with the consequent cracking of the concrete tunnel lining and its resultant outward leakage was so slight that if it had occurred out in the country, no remedy would have been called for.

The economy of this policy has proved to be many hundreds of thousands of dollars. Furthermore, the alternative for the deep pressure tunnels in rock was metal pipe construction. Difficulties would have been increased a thousandfold, especially within the City by the use of pipes. The pipes would have been of relatively short life. North of the City line at least three very large steel pipes would have been required for each pressure tunnel. Within the City much smaller pipes would have been demanded by street conditions; 16 steel pipes 66 inches in diameter or 30 cast-iron pipes 48 inches in diameter would have been needed. Pressure tunnels as a substitute for pipes within the City alone saved at least $15,000,000 in present-day expenditures, not to mention the avoidance of great expense for renewals at a later day and the intolerable annoyance of such extensive pipe-laying in the busy City thoroughfares.

A full circle panorama of New York City's streets around Madison Square showing Shaft 18 and a portion of the City tunnel in the rock more than 200 feet beneath the surface. Madison Square Garden tower, the Metropolitan tower and Flatiron Building are easily recognized from left to right.

A stretch of difficult tunneling where the seamy and broken character of the rock required the roof of the tunnel to be supported by strong steel work, on posts bearing on the more solid rock below. The steel was imbedded in the concrete when the tunnel was lined.

STATISTICAL ITEMS OF INTEREST IN CONNECTION WITH THE CATSKILL MOUNTAIN WATER SUPPLY

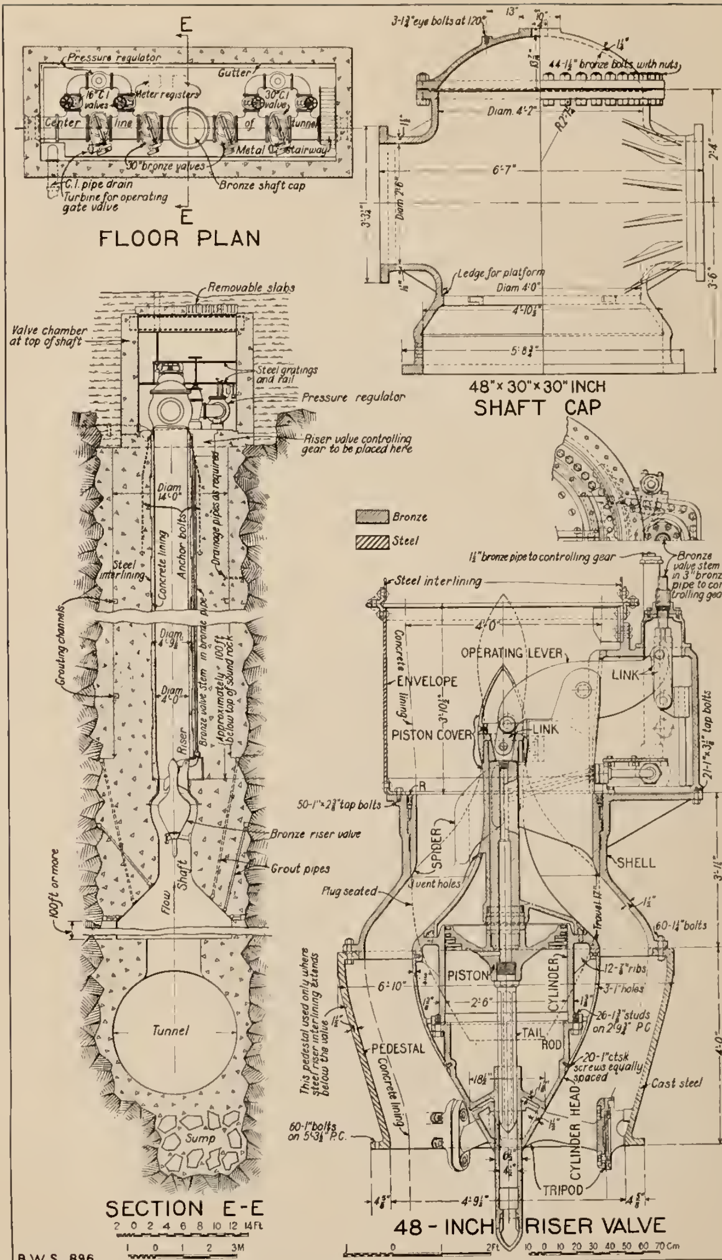
Maximum Construction Progress

Monthly Progress

Grade tunnel excavation..........	425	linear feet
(Contract 12, Bonticou tunnel; Hudson River shale; excavation 19 feet high, 16½ feet wide; 10.5 cubic yards per linear foot)		
Pressure tunnel excavation..........	530½	linear feet
(Contract 47, Wallkill pressure tunnel; Hudson River shale; excavation circular, 18½ feet in diameter; 10 cubic yards per linear foot)		
Shaft excavation	183	linear feet
(Contract 80, Breakneck pressure tunnel shaft; Storm King granite; excavation circular, 17½ feet in diameter; 8.9 cubic yards per linear foot)		
Concreting cut-and-cover aqueduct..........	1,740	linear feet
(Contract 15; approximately 8,800 cubic yards of concrete were placed from one plant; about 5 cubic yards per linear foot)		
Concreting grade tunnel	2,453	linear feet
(Contract 2, Garrison tunnel; approximately 6,900 cubic yards of concrete were placed in two directions from one central mixing plant at foot of shaft; 2.8 cubic yards per linear foot, excluding invert of 0.18 cubic yard per linear foot, placed subsequently)		
Concreting pressure tunnel..........	2,834	linear feet
(Contract 67, City tunnel; diameter of finished tunnel, 12 feet; 9,470 cubic yards of concrete were placed; 3.34 cubic yards per linear foot, excluding invert of 0.61 cubic yard per linear foot, placed previously)		
Concreting shaft	310	linear feet
(Contract 80, Breakneck pressure tunnel shaft; diameter of finished shaft, 14 feet; the concrete placed averaged 3.6 cubic yards per linear foot; the 310 feet were lined in 22 days, elapsed time)		
Placing masonry in Kensico dam, Contract 9..........	84,450	cubic yards

Weekly and Daily Progress

Laying 66-inch steel pipe	week	1,409	linear feet
	day	360	linear feet
(Contract 86, part of Queens conduit; one 8-hour shift per day; pipe length, 30 feet)			
Laying 48-inch cast-iron pipe	week	1,748	linear feet
	day	312	linear feet
(Contract 86, part of Queens conduit; one 8-hour shift; pipe length, 12 feet)			
Laying 36-inch submerged pipe	week	984	linear feet
	day	228	linear feet
(Contract 99, Narrows siphon; three 8-hour shifts; pipe length, 12 feet)			



Sections of a typical shaft and chamber of the City tunnel, with details of a riser valve and shaft cap

Weights of Some Large Special Valves and Fittings

Cast-steel dome on top of Drainage shaft, Hudson tunnel	46.25 tons
Bronze section valve, City tunnel, 66-inch	20.5 tons
Bronze riser valve, City tunnel, 72-inch	21.4 tons
Bronze riser valve, City tunnel, 48-inch	9.4 tons
Bronze shaft cap, City tunnel, 72-inch by 48-inch by 48-inch	11.8 tons
Bronze shaft cap, City tunnel, 48-inch by 30-inch by 30-inch	4.8 tons

Elevations Above Tide in New York Harbor of the Water at Various Points Along the Catskill Aqueduct

Ashokan reservoir, East basin	587 feet
Ashokan reservoir, West basin	590 feet
Aqueduct at headworks (flow line)	511 feet
Kensico reservoir	355 feet
Aqueduct at Kensico Lower gate-chamber	330 feet
Water level, Eastview filters	322 feet
Aqueduct at filter effluent (flow line)	312 feet
Hill View reservoir	295 feet
Silver Lake reservoir	228 feet

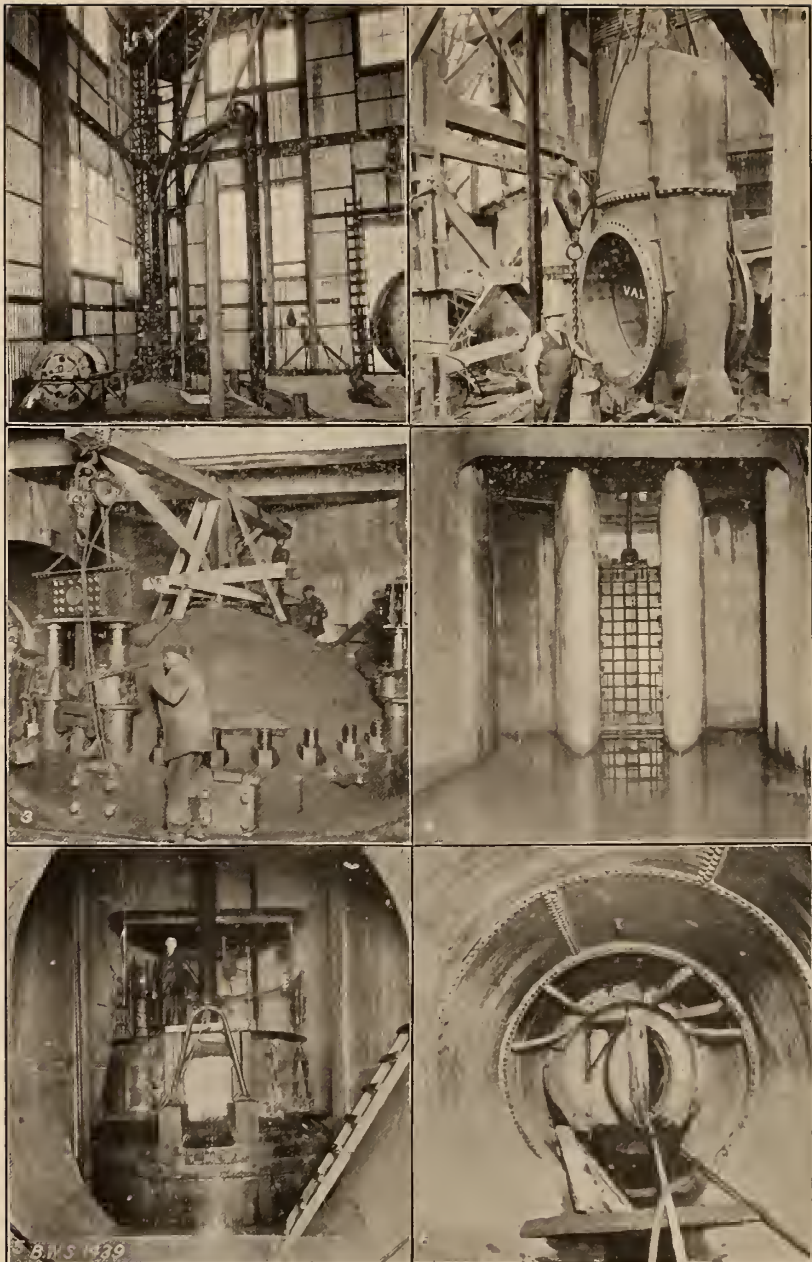
When the City tunnel is in service, water can be delivered in lower Manhattan at an elevation 260 feet above tide level and in Brooklyn about 240 feet above tide level, under working conditions.

Distances from Ashokan Reservoir

To Hudson River crossing	45 miles
To Croton lake	64 miles
To Kensico reservoir	75 miles
To Hill View reservoir (New York City line)	92 miles
To Silver Lake reservoir	119 miles

Principal Total Construction Quantities

Earth excavation in open cut	16,000,000 cubic yards
Earth excavation in tunnel	50,000 cubic yards
Rock excavation in open cut	1,000,000 cubic yards
Rock excavation in tunnel	2,700,000 cubic yards
Masonry in open cut	4,200,000 cubic yards
Masonry in tunnel	1,100,000 cubic yards
Cement	6,700,000 barrels
Cast iron	27,000 tons
Steel	32,000 tons
Bronze and brass	3,000,000 pounds



The building over a drainage shaft showing the discharge pipe and power, lighting and telephone cable reels (1); (2) a huge bronze valve ready to be lowered into a City Tunnel shaft; (3) the steel dome and anchor bolts on top of the Hudson Drainage shaft; (4) the connection chamber and a sluice-gate at the junction between a steel-pipe siphon and cut-and-cover aqueduct; (5) the unwatering equipment in the Hudson pressure tunnel, at the bottom of the drainage shaft; (6) the bronze door in a drift connecting an offset drainage shaft with a pressure tunnel.

Brief Chronology of Catskill Mountain Water Works

Report to Manufacturers' Association; sources west of Hudson river considered for Brooklyn	March 15, 1897
John R. Freeman's report submitted to Comptroller Coler	March 23, 1900
Burr-Hering-Freeman Commission's report rendered to Mayor Low	November 30, 1903
Constitutional amendment passed exempting water-supply bonds from debt limit	November 8, 1904
Board of Water Supply Commissioners appointed by Mayor McClellan	June 9, 1905
Chief Engineer began his duties	August 1, 1905
Report to Board of Estimate and Apportionment, recommending development of Catskill Mountain watersheds, submitted	October 9, 1905
Plan for this development adopted by Board of Estimate and Apportionment	October 27, 1905
Plan filed with State authorities for approval	November 3, 1905
Development of watersheds of Esopus, Rondout and Catskill creeks approved by State authorities	May 14, 1906
Experimental shaft, now West shaft, of Hudson pressure tunnel, begun	February 23, 1907
Contract 2, the first for aqueduct construction, embracing 11 miles between Cold Spring and Hunters brook, awarded	March 27, 1907
First sod turned, with appropriate ceremonies, by Mayor McClellan, near Garrison	June 20, 1907
Contract 3, for the Main dams of Ashokan reservoir, awarded	August 26, 1907
Police bureau established	February 28, 1908
First concrete placed for aqueduct structure, near Peekskill	April 28, 1908
First masonry laid for Olive Bridge dam, Ashokan reservoir	September 19, 1908
Contract 30, for Hill View reservoir, awarded	December 10, 1909
Contract 9, for Kensico reservoir, awarded	December 24, 1909
Contracts 63, 65, 66 and 67, for the City tunnel, awarded	May 26, 1911 June 5, 1911
Maximum contractors' forces, 17,243 men, at active field work	August 23, 1911
Maximum contractors' earnings, $2,214,000 for month	November, 1911
Headings of Hudson pressure tunnel met, and "holing through" shot fired by Mayor Gaynor	January 30, 1912
Bureau of Claims established	July 9, 1912
Storage of water in Ashokan reservoir begun	September 9, 1913
Last heading in City tunnel between Shafts 8 and 9, "holed through" by Mayor Mitchel	January 12, 1914
Authority to develop Schoharie watershed obtained from State authorities	October 21, 1914
Began filling Kensico reservoir with Catskill water	November 22, 1915
Began filling Hill View reservoir with Catskill water	November 30, 1915
First delivery of Catskill water into distribution pipes of New York City *	December 27, 1915

*Small quantities mixed with Bronx River water, had been supplied to Williamsbridge district through Bronx conduit during the last week of November, 1915.

Laying the Narrows siphon from Brooklyn to Staten Island. At the left is the clam-shell dredge boat with its scows and at the right the pipe-laying barge and the submerged bridge used to support the pipe-line as it was put together. The barge and bridge were moved forward as the pipes were added to the line so that the pipe-line was paid out like a chain into the bottom of the trench. Subsequently the pipe was covered over witb sand and gravel.

Brief Chronology of Catskill Mountain Waterworks (continued)

Report of Merchants' Association to Board of Estimate and Apportionment urging development of Schoharie creek without delay	January 7, 1916
State Conservation Commission approved amended Schoharie plan	June 6, 1916
Transfer of maintenance of Esopus watershed and operation of completed reservoir and aqueduct structures, to Department of Water Supply, Gas and Electricity.............	August 1, 1917
Bids opened for Shandaken tunnel from Schoharie reservoir to Esopus creek	September 11, 1917
Civic celebration of introduction of Catskill water into New York City	October 12, 13, 14, 1917

Statistics of Ashokan, Kensico and Schoharie Reservoirs

	Ashokan	Kensico	Schoharie
Capacity, total	132,000,000,000 gallons	38,000,000,000 gallons	22,000,000,000 gallons
Capacity, available...	128,000,000,000 gallons	29,000,000,000 gallons	20,000,000,000 gallons
Water surface	12.8 square miles= 8,180 acres	3.5 square miles=2,218 acres	1,170 acres
Land acquired	23.8 square miles=15,222 acres	7.0 square miles=4,500 acres	3.70 square miles=2,372 acres*
Elevation of top of dam, above tide....	610 feet	370 feet	1,150 feet
Length of reservoir..	12 miles	4 miles	5 miles
Length of shore line.	40 miles	30 miles	12 miles
Length of dams and dikes	5½ miles	3,300 feet	2,100 feet
Main dam:			
total length	4,650 feet	1,825 feet	2,100 feet
length of masonry portion	1,000 feet	1,825 feet	1,600 feet (Earth, 500 feet)
hight (maximum)..	240 feet	307 feet	....
thickness at base (maximum)	190 feet	235 feet	165 feet
thickness at top (minimum)	23 feet	28 feet	....
Width of reservoir:			
maximum	3 miles	3 miles	4⁄5 mile
average	1 mile	1 mile	2⁄5 mile
Depth of reservoir:			
maximum	190 feet	155 feet	150 feet
average	50 feet	52 feet	58 feet
Villages submerged..	7	1	1
Permanent population of submerged area at beginning of work	2,000	500	350
Cemeteries removed..	32	none	3
Bodies reinterred....	2,800	none	935
Railroad relocated...	11 miles	none	none
Highways discontinued	64 miles	14.8 miles	13 miles
Highways built	40 miles	15.1 miles	13 miles
Highway bridges built	10	4	2
Earth and rock excavation	2,500,000 cubic yards	1,400,000 cubic yards	725,000 cubic yards (For dam only)
Embankment	7,300,000 cubic yards	2,010,000 cubic yards	681,000 cubic yards (For dam only)
Masonry	900,000 cubic yards	965,000 cubic yards	319,000 cubic yards (For dam only)
Cement	1,200,000 barrels	897,000 barrels	350,000 barrels (For dam only)
Maximum number of men employed	3,000	1,500	†

*Proceedings just begun. †Construction not yet begun.

OFFICERS AND ENGINEERS OF THE BOARD

Commissioners

J. Edward Simmons, President, 1905–1908
John A. Bensel, President, 1908–1910
Charles Strauss, President, 1911–date
Charles N. Chadwick, 1905–date
Charles A. Shaw, 1905–1911
John F. Galvin, 1911–date

Secretaries

Thomas Hassett, 1905–1910
Thos. H. Keogh, 1910–1911
Joseph P. Morrissey, 1911–1914
W. Bruce Cobb, 1914–1915
George Featherstone, 1915–date

Assistant Secretaries

Harold G. Murray, 1905–1906
Edw. S. Brownson, Jr., 1907–1910
Frederick Evans, 1908–1911
Joseph P. Morrissey, 1910–1911
Michael B. Stanton, 1911–1912
John M. Wilson, 1911–1914
Ralph T. Stanton, 1912–date

Auditor

Henry C. Buncke, 1905–date

Adjusters of Taxes and Assessments

Frederick Evans, 1908
Mark Eustace, 1908–1914

Examiner of Real Estate, Taxes and Legislation

A. F. Britton, 1907–1917

Chiefs of Patrolmen-on-Aqueduct

Rhinelander Waldo, 1908
Douglas I. McKay, 1908–1911
Richard H. Burke, 1911–1912
George F. Shrady, 1912–1917

Chief of Bureau of Claims

Walter Le C. Boyer, 1912–date

Engineering Bureau

Chief Engineer

J. Waldo Smith, 1905–date

Deputy Chief Engineers

Charles L. Harrison, 1909–1910
Merritt H. Smith, 1910–1914
Alfred D. Flinn, 1914–date

Department Engineers

Alfred D. Flinn, 1905–1914
Robert Ridgway, 1905–1912
Carleton E. Davis, 1905–1912
Merritt H. Smith, 1906-1910
William W. Brush, 1909–1910
Thaddeus Merriman, 1910–date
George G. Honness, 1912–date
Ralph N. Wheeler, 1912–1917
Frank E. Winsor, 1910–1915
Walter E. Spear, 1910–date

Consulting Engineers

John R. Freeman, 1905–date
Frederic P. Stearns, 1905–date
William H. Burr, 1905–date
Alfred Noble, 1909–1914

Specialists

W. O. Crosby, James F. Kemp, Charles P. Berkey, geologists; Allen Hazen, Geo. W. Fuller, treatment of water and watershed sanitation; Pease and Provost, camp and watershed sanitation; Charles W. Leavitt, landscape engineering; York and Sawyer, consulting architects; Arthur H. Blanchard, highway engineering; R. J. Colony, cement investigations.

BOARD OF WATER SUPPLY FORCES

BUREAU	Oct. 1, 1917*	MAXIMUM AT VARIOUS DATES
Commissioners	3	3
Administration bureau	37	66
Police bureau	58	387
Engineering bureau:		
Chief Engineer and staff	11	13
Headquarters department	129	260
Reservoir department	143	236
Northern Aqueduct department	36	630
Southern Aqueduct department	64	318
City Aqueduct department	100	209
Total, Engineering bureau	483	
Total, Board of Water Supply	581	
Engineering bureau; maximum force at any one time		1,348
Maximum total forces of the Board		1,757

* Including employees absent on military duty or civilian duties connected with the war.